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Floodplains, flooding, and salmon rearing habitats in British Columbia: A review

Examen des plaines d'inondation, des inondations et des habitats d'alevinage du saumon en Colombie-Britannique

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Abstract

The purpose of this review paper was to examine the relationships between floodplains, flooding, and juvenile salmon habitats. A wide range of topics were explored, these include; defining and characterizing fish habitats and floodplains; explaining flooding and hydrological processes; and outlining fish behaviours, diets, and ecology. The potential impacts of forestry, agriculture, and urban development on floodplain processes, fish stranding, and fish habitats were explored. This includes a short discussion on chemicals and pollutants that enter fish habitats as a result of human activities on floodplains. In developing an understanding of our current knowledge of floodplain habitats and in identifying significant knowledge gaps, over 500 references were cited. This review was focused on British Columbia's floodplains but does contain references to research done elsewhere.

Social values exceed environmental concerns on a developed floodplain and few viable options remain. A major flood can cause loss of life and tremendous property damage. Thus, humans tend to view floods with fear. From an ecological perspective flooding is a natural event and an integral part of salmonid life cycles. When a river is separated from it's floodplain and held to a permanent course by dykes, considerable loss of salmonid habitat will eventually result. We can not maintain natural flooding patterns or regain many of the historic floodplain fish habitats, once floodplains have been urbanized. We can only protect the remaining critical habitats from development.

On an undeveloped floodplain, consideration can be given to limiting activities to those that are consistent with maintaining natural systems. It is important that we maintain the natural hydrograph, permit the flooding of floodplains, support the natural avulsion of a river channel, and protect wetlands. From an ecological prospective, floods are natural and are important in maintaining the health of the river, riparian zone, and floodplain. Fish and invertebrates are adapted to seasonal flooding. Periods of high water may serve as a queue for migration or an opportunity to move into and exploit different habitats. Floods create new channels and a succession of new habitats while eliminating others. Floods clean the substrate and alter the species composition of the riparian communities.

The wetlands associated with floodplains support the rearing of juvenile salmon. Floodplains provide habitat for juvenile salmonids in the form of seasonal wetlands, temporary tributaries, off-channel ponds, sloughs, flood-channels and seasonal estuarine drainages. Natural floodplains reduce the heights of floods, storing floodwaters in wetlands, and distributing the floodwaters over a wide area. They also filter storm waters, trapping sediments, nutrients, and removing pollutants. Floodplains are a major source and processor of litter. When compared to lentic habitats, these seasonal habitats support a different mix of invertebrates, usually have more modified water temperatures, and may have different water quality concerns. Many of these habitats support higher densities of juvenile salmon and have higher grow rates than main channel habitats.

Coastal and interior floodplain habitats are used by a number of regionally important salmon species. These fish appear to have adapted behaviours that enable them to successfully exploit seasonally flooded lands. Human activities such as forestry, agriculture, and urban development can affect salmonid floodplain habitats. Based on this review, some major gaps in our knowledge and concepts we should consider when examining floodplains are listed below.

Résumé

Cet article de synthèse porte sur l'examen des relations entre les plaines d'inondation, les inondations et les habitats du saumon juvénile. Une vaste gamme de sujets sont abordés, tels que la définition et la caractérisation des habitats du poisson et des plaines d'inondation, l'explication des processus d'inondation et des processus hydrologiques et un survol des comportements, des régimes alimentaires et de l'écologie du poisson. Les incidences potentielles de la foresterie, de l'agriculture et du développement urbain sur les processus des plaines d'inondation, le poisson et ses habitats sont examinés, incluant une courte discussion sur les produits chimiques et les polluants introduits dans les habitats du poisson suite aux activités humaines menées dans les plaines d'inondation. Plus de 500 études ont été consultées afin d'établir l'état de nos connaissances sur les habitats des plaines d'inondation et d'y identifier les lacunes importantes. Bien que cet examen visait les plaines d'inondation de la Colombie-Britannique, des références sur des recherches menées ailleurs sont aussi présentées.

Les valeurs sociales l'emportent sur les préoccupations environnementales à l'endroit des plaines d'inondation. Peu d'options viables sont donc disponibles. Comme les graves inondations peuvent causer des pertes de vie et des dommages gigantesques aux biens, nous avons tendance à les craindre. Du point de vue écologique, une inondation est un événement naturel qui fait partie intégrante des cycles de vie des salmonidés. Lorsqu'une rivière est isolée de sa plaine d'inondation et confinée à un tracé permanent par des digues, une perte importante d'habitat des salmonidés en résultera éventuellement. Il est impossible de maintenir les régimes d'inondation naturels ou de recouvrer nombre des habitats du poisson autrefois présents dans les plaines d'inondation une fois celles-ci urbanisées. Tout ce que nous pouvons faire, c'est protéger les habitats essentiels restants du développement.

Dans une plaine d'inondation non aménagée, on peut songer à limiter les activités à celles qui favoriseront la pérennité des systèmes naturels. Il est important de conserver l'hydrographie naturelle, de ne pas empêcher les inondations, de favoriser l'avulsion naturelle et de protéger les terres humides. Du point de vue écologique, les inondations sont un événement naturel et important pour le maintien en bon état d'un cours d'eau, de sa zone riveraine et de sa plaine d'inondation. Les poissons et les invertébrés sont adaptés aux inondations saisonnières. Ainsi, les périodes de crue peuvent leur servir de signal pour la migration ou leur offrir l'opportunité de pénétrer dans différents habitats et de les exploiter. Les inondations créent de nouveaux chenaux et une panoplie de nouveaux habitats, tout en en détruisant d'autres. En outre, elles nettoient le substrat et modifient la composition taxinomique des communautés riveraines.

Les terres humides caractéristiques des plaines d'inondations sont essentielles aux activités d'alevinage des salmonidés juvéniles. Ces plaines leur offrent des habitats sous forme de terres humides saisonnières, d'affluents temporaires, d'étangs hors chenal, de faux chenaux, de chenaux de hautes eaux et de plans d'eau estuariens saisonniers. Les plaines d'inondation naturelles réduisent le niveau des inondations, emmagasinant les eaux de crue dans les terres humides et les distribuant sur une vaste étendue. Elles filtrent aussi les eaux pluviales, piégeant les sédiments et les nutriments et enlevant les polluants. Les plaines d'inondation sont une source majeure et un important transformateur de litière. Comparativement aux habitats lénitiques, ces habitats saisonniers abritent un mélange différent d'invertébrés, offrent généralement des températures de l'eau davantage modifiées et ne souffrent pas des mêmes problèmes de qualité de l'eau. Un grand nombre de ces habitats accueillent des densités plus élevées de saumons juvéniles et permettent des taux de croissance plus élevés que ceux retrouvés dans les habitats du chenal principal.

Diverses espèces de saumon importantes au niveau régional utilisent les habitats des plaines d'inondation côtières et intérieures. Ces poissons semblent avoir adapté leur comportement pour leur permettre de tirer profit des terres inondées sur une base saisonnière. Certaines activités humaines, comme la foresterie, l'agriculture et le développement urbain, peuvent nuire aux habitats des salmonidés dans les plaines d'inondation. Quelques lacunes importantes dans les connaissances et certains concepts qui devraient être considérés dans l'évaluation des plaines d'inondation, identifiés lors de cet examen, sont présentés ci-dessous.

Knowledge Gaps and Recommendations

1. The relationship between coho and cutthroat trout within coastal seasonal wetlands should be studied. There appears to be resource partitioning. Coho juveniles occupy the most marginal, shallow, ephemeral sites while cutthroat trout occupy deeper, more permanent waters. This has implications for habitat enhancement. How deep and large should an off-channel over-wintering site be? In developing off-channel habitats are we enhancing trout habitat instead of coho habitat when we change the nature of the sites?
2. The role of non-natal estuarine drainages as winter habitat should be examined. It is not clear if this type of habitat is commonly used or if it is important in specific situations. This has major implications for how we survey and manage very small coastal drainages that border known salmon streams.
3. The relationship between coastal lake margins, flooding, and salmonid use of flooded lands bordering lakes, has not been examined. This knowledge may assist future decisions regarding lake riparian setbacks and foreshore development.
4. Considerable research is required to document and understand the use of seasonal flooded lands in the interior of B.C. by juvenile salmonids. It is not clear if juvenile salmonids move off-channel at peak flow and some are fortuitously stranded within suitable over-wintering locations or if the movements are part of a life history strategy similar to that noted on the coast. We have no clear description of what flooded lands are used, estimate of how many fish use them, residency time, understanding of fish diet or behaviour. Stranding may be related to opportunistic feeding on flooded lands or to lateral displacement during downstream movements.
5. The relationship between flooding, pond size, connectivity, and benthic communities has not been examined.
6. The role of UVR on invertebrates and juvenile salmonids should be examined in relation to the flooding of an interior lake's foreshore during June-July.
7. The impact of ranching on seasonally flooded meadows and wetlands, (possible fish habitat) has not been examined. Anecdotal observations of stranding within fields and irrigation ditches are common.
8. The identification of coastal off-channel sites prior to forest harvest is considered the key to prevention of damage to juvenile salmonid floodplain habitats. Winter ground surveys are recommended.
9. Flow control systems should attempt to maintain the natural hydrograph. Where considerable downstream off-channel habitat exists in a coastal system, the first storms of autumn provide the queue and opportunity to access those sites.
10. Ground water sources appear to be extremely important in interior systems. Locations of ground water sources utilized by juvenile salmonids should be identified and protected.

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Introduction

Purpose and Objectives

The purpose of this review paper is to examine the relationships between floodplains, flooding, and regionally important fish species. Considerable effort was spent in collecting literature relevant to this topic and in identifying subject areas where more research may be required. Habitat management staff must make decisions regarding the impacts of land-based activities on fish habitat associated with floodplains. A clear understanding of our current knowledge of floodplain habitats and its use by salmon and trout would provide support for those decisions. The recognition of significant knowledge gaps should provide a focus for future research activities. This review is focused on B.C. floodplains but contains references to research done elsewhere. A small amount of unpublished data has been added and a number of observations by fisheries personnel have been included.

The Agricultural Focus Group (Chair), requested scientific support through PSARC, to improve decisions being made by habitat management biologists concerning floodplain habitats. The author was asked to address the following questions:

1. What floodplain habitats are used by regionally important fish species?
2. Does agriculture, urban development, and forest harvesting influence juvenile salmonid habitat use during high water?
3. Is stranding a problem? Do human activities change the likelihood of stranding? What situations provide good access to and from floodplain habitats and which result in stranding?
4. What are the benefits of having refuge during high water? What are the risks of being stranded or flushed out of a small stream prematurely?
5. What food (allochthonous), nutrients, insects, chemicals come from flooded lands of different types? How do they impact on fish?

In addressing these questions a considerable range of topics must be explored. These include defining and characterizing fish habitats and floodplains; explaining flooding and hydrological cycles; outlining fish behaviours, diets, ecology, and strategies; and assessing the potential impacts of forestry, agriculture, and urban development on floodplain processes and fish habitats. It was understood that management issues such as: guidelines, standards, development setbacks, riparian buffer widths, review of development policies, and an examination of methods used to protect fish habitat on floodplains would be dealt with in a separate paper.

Seasonally flooded lands in British Columbia do contain habitats utilized by regionally important salmon and trout stocks. In this paper I will examine the relationship between salmon and trout species, flooding, and floodplain habitats. I will emphasis those fish species that appear to have life history patterns linked to flooding cycles and floodplain habitats. The ecology of juvenile salmonids will be a focus of this paper. The timing of fish movements may be initiated by hydrological conditions and are an adaptive response to flooding and water temperature. I have attempted to separate the discussion of salmonid floodplain habitats into coastal and interior sections based on rain-dominated and snowmelt dominated hydrological process. This division is not always clear but was necessary to reduce duplication.

In this manuscript it is not possible to examine every floodplain, describe every possible impact of flooding, every possible response of fish to flooding, or all potential impacts of forestry, agriculture and urban development on hydrology, water quality, and floodplain habitat. Considerable differences exist in forest harvesting practices, agricultural practices, and rates of urban development, throughout B.C. Also, each watershed has its own set of physical characteristics (e.g. size of floodplains, gradient, area of lakes and wetlands, type of terrain, etc) which makes it unique.

Organization

This paper is divided into three sections. The first section describes rain-dominated coastal habitats. The hydrographs of rain-dominated and glacial melt watersheds are described. The relationships between autumn-winter flooding and coastal riverine (floodplain), lacustrine (small ponds and lakes) and estuarine (small coastal estuaries) rearing habitats is emphasised. On the rain-dominated coastal floodplains juvenile coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*O. clarki clarki*) winter habitats will be examined in detail. These are the fish species most closely associated with coastal floodplains and have been documented to use flooded off-channel winter habitats. Literature on hydrology and salmon winter rearing habitats in riverine and palustrine (swamp) habitats on coastal floodplains is abundant. Considerably less information is available on salmon winter use of small coastal estuaries and use of seasonal estuarine drainages (non-natal seasonal streams). Although coho juveniles have been documented to use lacustrine habitats (small coastal lakes) the relationship between them and flooded lake margins is not clear.

The second section describes snow-dominated interior watersheds and fish response to flooding. For interior watersheds, an understanding of the relationships between floodplain habitats and fish utilization is not as simple as it is for coastal systems. Although June and July are the months of flooding, the juveniles of a number of salmon species must rear through the late summer, autumn, and winter in isolated floodplain sites. Thus, an examination of spring, summer, and winter ecology of a number of salmon species is required. In interior snow-dominated watersheds coho, chinook salmon (*O. tshawytscha*) and rainbow trout or steelhead (*O. mykiss*) ecology and habitats will be described. The relationships between snow dominated flooding (June) and off-channel habitats is not as well documented for interior rivers as it is for coastal watersheds. Information on interior lake foreshore flooding is also very limited. This section also contains a short discussion on fish habitats associated with the Fraser River Estuary. These habitats are influenced by a combination of flooding from the Fraser River in June, flooding of small lowland tributaries in winter, and flooding during high tides.

The third section will examine the potential impacts of human activities on hydrology and floodplain habitats. The impacts of forestry, urban development and agriculture will be reviewed. Literature on the impacts of forestry activities on the storm hydrographs for both rain and snow dominated regions is abundant. Considerable literature is available on the impacts of forestry activities on coastal watersheds; slightly less is available on interior watersheds. However, the specific impact of forestry activities on off-channel habitats is very limited, especially as it relates to interior watersheds.

In reviewing the impacts of urban development on floodplain habitats it became apparent that many of the major subject areas had already been examined in detail. The impacts of urban development and agriculture within the Fraser River basin has been well documented in the numerous publications of the "Fraser River Action Plan" and these are available on the Internet. This review highlights some of the issues related to habitat loss and isolation (e.g. hydromodification and transportation corridors). It examines water quality concerns associated with agricultural and urban runoff and looks at water quantity and hydrological processes that are altered through flow control and urban development.

Nature of Flooding

Flood rivers are those where large seasonal variations in precipitation (and melt) are transmitted down river as a pulse of increasing flow (Welcome 1979). Watersheds can be roughly divided into two basic types, rain-dominated and snow-dominated (Melone 1985). However, this division is not always clear. Natural rivers and streams in British Columbia can be considered to be flood rivers when they are subjected to seasonal variations in discharge associated with rain, snowmelt, glacial melt, and rain-on-snow on events. Pulses of high water and flooding are associated with these hydrological processes. Some rivers may have both rain and snow dominated peak flows (e.g. Pitt River) and the hydrographs of some rivers are strongly influenced by glacial melt waters (e.g. Homathko River). Flooding of habitats in the Fraser delta may be influenced by June snow-melt flooding from the Fraser River, winter rains and runoff from coastal lands, and tidal cycles in the many sloughs, marshes, and channels of the lower river. The lower reaches of some Fraser Valley streams flow into and are inundated by Fraser River water during high snow melt peak floods (e.g. Salmon River, Langley prior to dyking).

Floods and fluctuating water levels are a normal part of all stream ecosystems. Plants and animals have evolved necessary behaviours and modifications to compensate for flooding waters. However, the natural process of flooding is pitted against the human struggle to control flooding and modify watersheds. In some cases the attempt to control flooding may lead to an increase in flood risk (Grizzell 1976) and dykes separate a river from its floodplain.

Definition of a Floodplain

A floodplain can be defined as "a valley bottom land form deposited by running water, which is at least occasionally inundated by water from the stream," (Cordes 1972). Bauer (1977) defined a floodplain as including "all lands that may be inundated by the possible maximum calculated flood." The contemporary floodplain can be defined as having a greater than 1 in 30 year flood recurrence interval (Millar et al. 1997). The active floodplain is defined as "that part of the contemporary floodplain subject to occupation by standing or flowing water more frequently than once in five years, on average" (Church and Eaton 2001). Church and Eaton (2001) suggested that for watersheds governed by purely fluvial processes, the 2-year flood should provide a reasonable index for bank-full stage.

Welcome (1979) viewed floodplains as appearing flat, but slight variations in elevation and slope could lead to great differences in the possibility of flooding and time of immersion at any locality on the plain. He listed and described typical features of floodplains. These features (the river channel, oxbow lakes, point bars, meander scrolls, sloughs, levees, back-swamp deposits and sand splays) are readily distinguishable on larger floodplains but are obscured in smaller valleys by the rapidity with which changes occur. Cowardin et al. (1979) defined the limits of the riverine system as the channel bank (including levees) or wetland dominated by trees, shrubs, and, persistent emergent vegetation. In braided streams, "the system is bounded by the banks forming the outer limits of the depression within which the braiding occurs". Bauer (1977) defined the floodway as consisting of "all active and old channels and adjacent lands required to carry the moving currents of the base flood flow." He also defined the floodway fringe as the "land outside of the floodway which the base flood inundates with flood-surge storage water of negligible down-valley currents." These terms are illustrated in Figure 1.

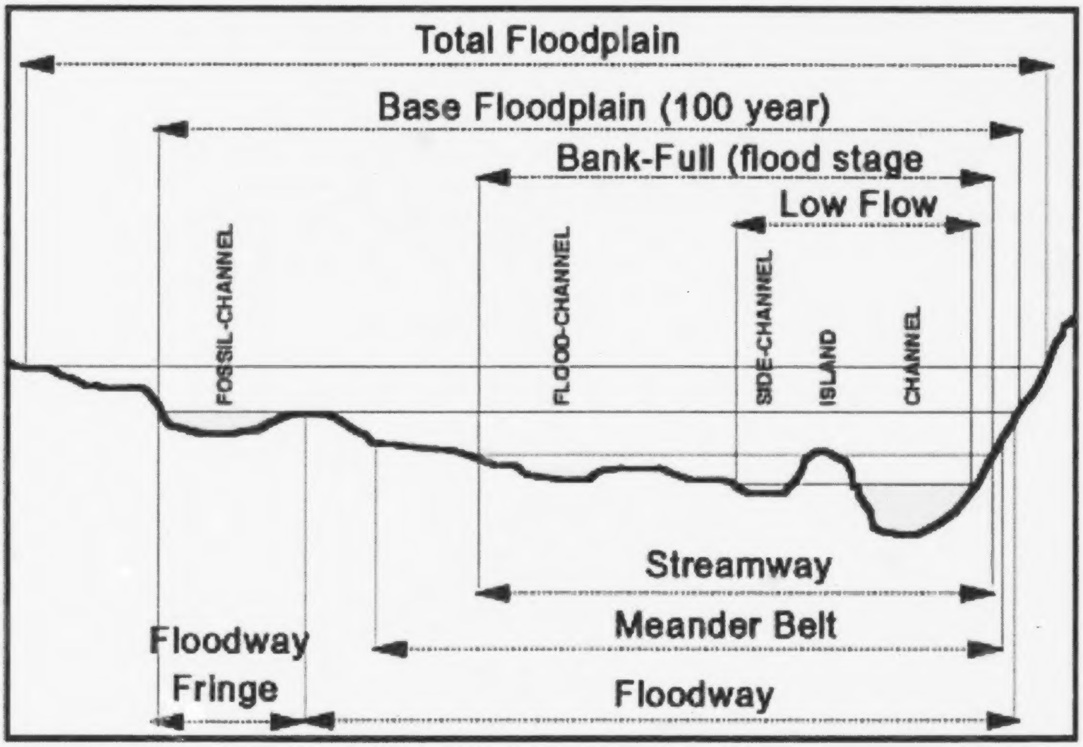


Figure 1. Attributes of a floodplain.

Not all areas that seasonally flood are associated with riverine alluvial floodplains. In the lacustrine environment, the foreshore and riparian edges of interior B.C. lakes are often seasonally flooded. In June, interior lake water levels may rise 3-4 m, flooding unconsolidated shores, emergent wetlands, and occasionally riparian lands. In autumn and winter, heavy rains may cause coastal lake levels to rise and temporarily flood surrounding lands. In coastal estuaries upper and lower marshes and small seasonal drainages may support winter rearing fish. In some systems, tides combined with seasonal flooding may provide access to emergent lands and sloughs. Cowardin et al. (1979) would classify these habitats as palustrine persistent emergent wetlands. Availability of such habitat is often associated with a combination of flood surge and high tide. The Lower Fraser River contains such habitat (Levy and Northcote 1982; Levings et al.1991, 1995).

Coastal Floodplains

Rain Dominated Hydrograph

Rain dominated watersheds are located on the coast at lower elevations. The extent of this physiographic region was defined by Melone 1985 as extending along the entire length of the province bounded to the east by the crest of the Coastal Mountain range. The majority of peak floods occur during the fall and winter months, controlled by macro-scale atmospheric processes (e.g. stalled low pressure over the Gulf of Alaska) and are rainfall induced. Extreme floods can occur on most drainage basins independent of size. For watersheds determined to have both a rainfall and snowmelt-induced flood regime, the rainfall floods are greater than the snowmelt floods (Melone 1985). These flood events are often of short duration (days), occur numerous times during the autumn and winter, and increases from base flow may be very rapid (Figure 2). Low flow usually extends from June to October.

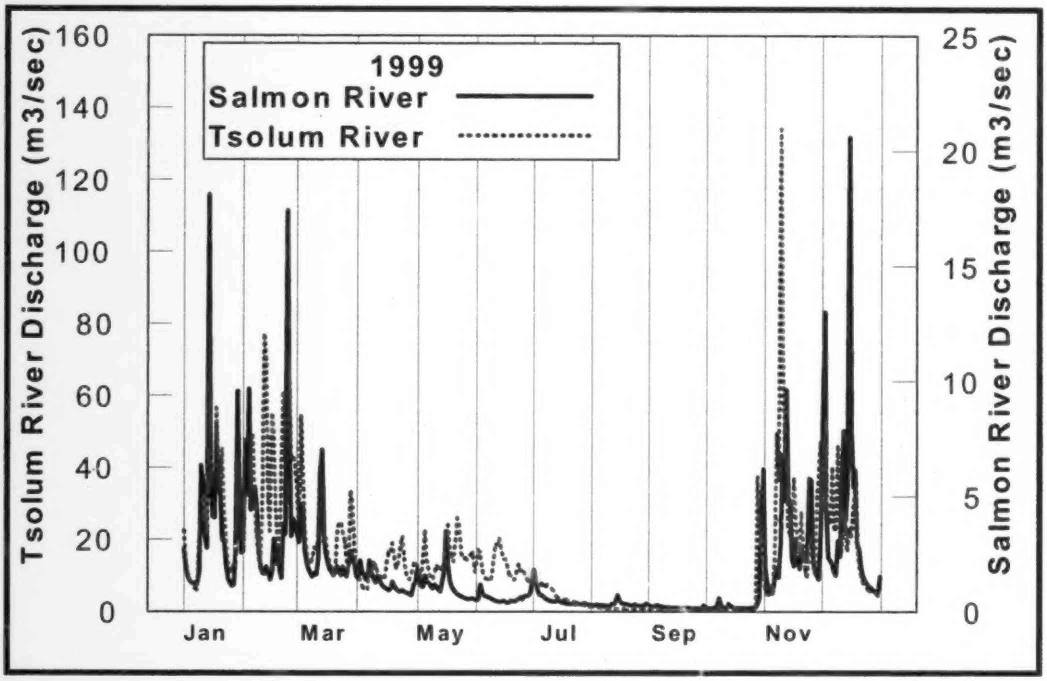


Figure 2. Annual hydrographs for two rain dominated B.C coastal watersheds, Salmon River near Langley and Tsolum River on Vancouver Island.

Rain dominated watersheds on Vancouver Island, the Fraser Valley, and coastal Washington, exhibit a low flow period from June to October. Summer, juvenile salmonid, rearing habitat may be limited in these watersheds due to a lack of rain and resultant low flows. This is not the case for coastal watersheds from mid coast B.C. to Alaska where a shifting jet stream may contribute considerable summer precipitation and maintain higher summer water levels.

Peak floods can also be caused by "rain-on-snow" events, in both coastal and interior watersheds. Watersheds that have a portion of their area in the "transient snow zone," a zone where both rainfall and rapid snowmelt occur at the same time, can be subject to floods. The transient snow zone is located from 650 to 1300 m (2000 to 4000 ft; Anderson and Hobba 1959) or 450 m to 1200m (Christner and Harr 1982) and is usually considered coastal in nature. The nature of "rain-on-snow" flood generation will be described in relation to snowmelt processes.

Glacial Watersheds

Glacier-melt dominated rivers are usually larger rivers located on the coast of B.C. and Alaska where a high portion of the watersheds drainage extends into the higher elevations and where headwater streams contribute substantial glacial melt to the lower river (Figure 3). Glacial melt rivers are often turbid as they contain suspended fine glacial particles (glacial flower). Peak discharge occurs during July and August when melt rates are highest. Extreme floods can occur and these are often related to the sudden release of ponded waters or break-off of a glacial section (C. Murray, personal communication). This phenomenon has been described for the Salmon River (British Columbia/Alaska) and Donjek River (Yukon) and is often called "glacier outburst floods" (Young 1980). Low flow often extends from December to March when the major portion of the watershed's precipitation is in the form of snow. In large coastal basins, different tributaries may be responding to different hydrological process. Thus, tributaries at lower elevations may be rain-dominated while others at higher elevations are subject to snow or glacial melt processes.

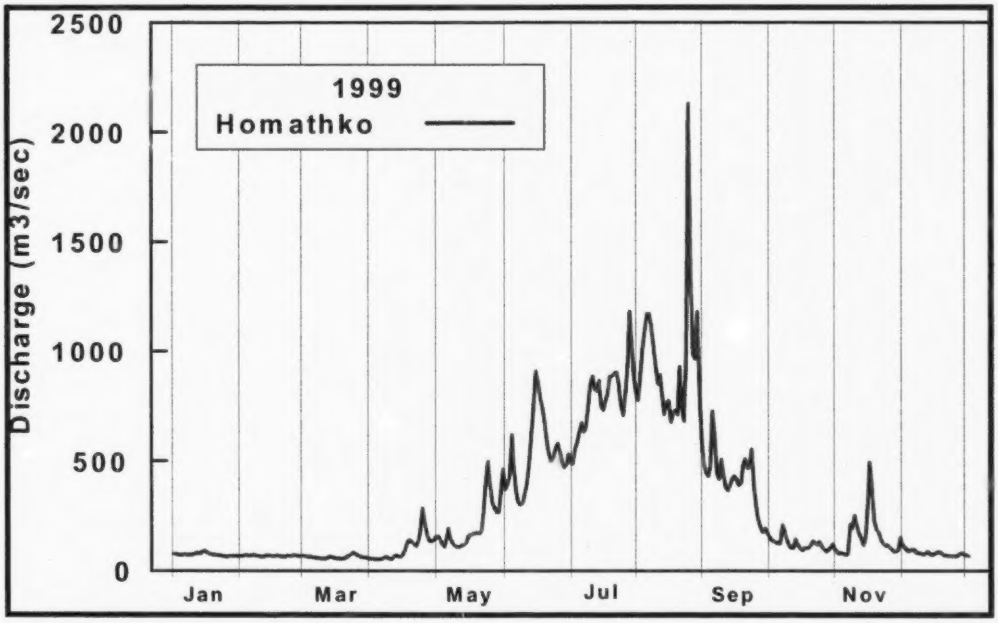


Figure 3. Annual hydrograph for the Homathko River, a glacial-melt-dominated watershed located mid-coast B.C.

Glacial-melt rivers are common in the interior of the province, but annual hydrographs for these rivers appear similar to snow-dominated watersheds. Peak discharge occurs in June-July and low flow occurs in March-April. However, water temperatures in the interior glacial melt systems are colder in summer than in other systems, the streams are often turbid, and water levels exhibit diurnal fluctuations. Tutty and Yole (1978) noted that chinook smolts from the glacial McGregor and upper Fraser Rivers bore scales having no freshwater annulus, while smolts from warmer interior rivers formed distinct freshwater annuli. This does imply a possible difference in salmonid rearing between glacial and non-glacial interior rivers.

Glacial rivers exhibit a strong diurnal stream discharge pattern based on the daily cycle of radiate energy (Figure 4). In June, the daily water level in the lower Homathko River can rise or fall 30-50 cm relative to solar inputs alone (warm rain at higher elevations can produce larger changes). In the lower river, peak daily discharge occurs at approximately 4:00 AM while low daily discharge occurs at approximately 2:00 PM. This daily flooding and subsiding of the river could have an impact on juvenile salmonid use of river edge habitat. In the main-stem of the glacial Situk River, Johnson et al. (1994) noted that young of the year salmonids occupied channel edges, whereas older juveniles occupied willow edges and debris pools. In the lower Homathko River the sampling of juvenile salmonids was a challenge due to turbid waters and constantly changing river shorelines (Kent Simpson, personal communication). Juvenile coho and chinook were captured in mid-summer within flooded backwaters located on the Homathko River floodplain. When lakes regulate discharge, settle suspended sediments, and increase water temperatures; salmon productivity is improved in those glacial rivers below the lakes (Dorava and Milner 2000).

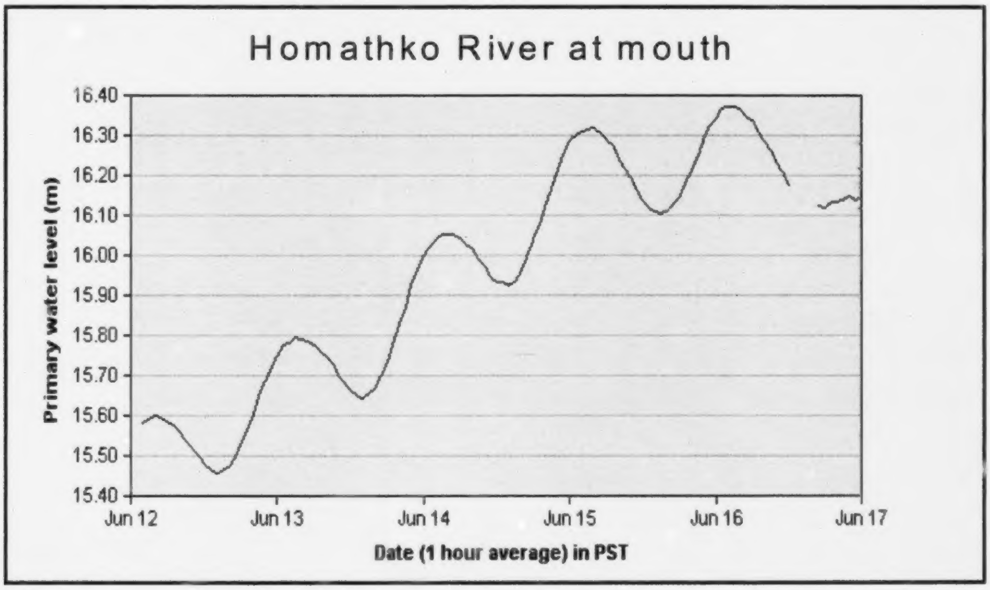


Figure 4. Homathko River hydrograph (June 12-16/02). Environment Canada WSC-Station 08GD004.

Coastal Fish Species

The opportunity of various fish species to utilize flooded lands or likelihood they will seek refuge in off-channel sites is dependent upon where they rear prior to flooding, their life history patterns, and behaviour in response to floods. Coastal rivers flood in autumn-winter, thus fish species that rear in freshwater through the summer are more likely to encounter situations in autumn where they have access to flooding lands. The life cycles of certain salmonid fishes have evolved to exploit the spatial and temporal variation in channel conditions (Sullivan et al. 1987). Coho and sockeye (*Oncorhynchus nerka*) salmon juveniles, Dolly Varden charr (*Salvelinus malma*), and steelhead and cutthroat trout, over-winter in coastal watersheds. Pink (*O. gorbusca*), chum (*O. keta*), and ocean-type chinook salmon juveniles leave freshwater prior to autumn floods.

It appears that in coastal watersheds steelhead juveniles do not redistribute on autumn freshets as coho and cutthroat do. Steelhead juveniles use interstitial spaces associated with course substrates in winter (Hillman et al 1987, Bustard and Narver 1975a,b) and occupy more permanent waters rather than seasonally flooded sites. In Carnation Creek, a small stream located on the west coast of Vancouver Island, there was little evidence that steelhead young used off-channel floodplain habitat (Hartman and Scrivener 1990, Hartman and Brown 1987). In the Clearwater River, Washington, Cederholm and Scarlett (1982) reported that steelhead juveniles avoided moving into riverine ponds yet dominated runoff streams. In winter in the Keogh River, eastern Vancouver Island, by far the highest juvenile steelhead densities were associated with the main river channel (Swales et al. 1988). Juvenile steelhead trout have been produced in higher than main river densities from side channels with controlled discharge (Mundie and Traber 1983). Hartman and Gill (1968) found steelhead fry and parr residing in larger rivers and small steep tributaries that drained directly into a large river. Steelhead trout juveniles are generally found in waters with higher velocities (Bisson et al. 1988) and have higher critical swimming velocity then other salmonids (Hawkins and Quinn 1996).

The life history patterns of Dolly Varden populations are very complex. Anadromous Dolly Varden charr juveniles may rear for up to four years before migrating downstream to the river mouths and near shore ocean areas (Scott and Crosman 1973). Dolly Varden were commonly captured in the estuary of the Squamish River, B.C. (Levy and Levings 1978). Non-anadromous stocks may rear for 3-4 years in streams before moving into a lake (Scott and Crosman 1973). There is a pronounced latitude variation in smoltification age, life span, and patterns of maturation (Gudkov 1996). Differences in migratory patterns exist between charr originating from watersheds with lakes and watersheds without lakes (Armstrong 1984). The existence of summer and autumn spawning groups further complicates life history patterns (DiCicco and Reynolds 1997).

Dolly Varden movements have been described as; an annual seaward feeding migration, upstream freshwater migration for overwintering, and a spawning migration (DiCicco and Reynolds 1997). Dolly Varden may migrate upstream to overwinter or may spend the winter in salt water (Bernard et al 1995). Dolly Varden have been reported to return to the same lacustrine watershed when overwintering in fresh water (Bernard et al. 1995) but conversely have demonstrated no fidelity to overwintering rivers (DeCicco and Reynolds 1997).

It is likely coastal Dolly Varden response to freshets and flood events. Their extended freshwater rearing period and complicated patterns of movements would support this view. Juvenile charr have been recorded moving upstream in autumn to overwinter within a spring-fed site within Spring Pond Creek, Alaska. (Elliot and Reed 1975). This behaviour appears similar to that of juvenile coho. However, Dolly Varden juveniles in the Coldwater River, B.C. overwintered within the interstitial spaces in the substrate, similar to rainbow trout juveniles (Swales and Levings 1989).

The coastal cutthroat trout resides within a zone that conforms closely to the Pacific coast rain forest belt (Trotter 1989, 1997) and they can exhibit a variety of life history forms (Trotter 1989; Garrett 1998). Coastal cutthroat trout have adapted life history traits (amphidromy, potamodromy, and residency) that are related to the local environment and make extensive use of the entire freshwater drainage (Garrett 1998). They tend to be more extensively distributed than other salmonids and are often found above barriers to anadromous fish (Northcote and Hartman 1988; Hartman and Scrivener 1990). They will occupy low gradient first and second order streams if water is present in summer, but will also utilize slightly higher gradient streams (> 4%) than coho salmon (Brown et al. 1989). Cutthroat trout, of different ages (Brown and Hartman 1988) winter rear and may spawn within intermittent tributaries associated with coastal floodplains (Hartman and Brown 1987). Small steams (<1.5m in width) contribute considerable summer (16%) and winter (23-57%) wetted stream length to coastal low-gradient watersheds (Rosenfeld et al. 2002). Thus, small streams provide considerable juvenile cutthroat trout rearing habitat. Coastal sea-run cutthroat trout seldom over-winter in saltwater, but return to freshwater (often non-natal streams) in the autumn of the year they go to sea (Trotter 1997).

A fish species that has life history strategies that regularly involve the use of flooded and seasonal wetted habitats is the coho salmon. Coho juveniles have been documented to use winter habitats isolated from the main channels on both interior (Swales et al. 1986) and coastal floodplains (Brown 1985). Their rearing strategies are particularly sensitive to seasonal patterns in river flow and water temperature. In this respect, river flow patterns help define the temporal availability of, and access to, coho winter rearing habitats located on coastal floodplains. The winter ecology of coastal juvenile coho salmon will be described in detail.

Habitat Components

Various authors have described salmonid habitats associated with coastal watersheds and their floodplains (Table 1). Juveniles may remain in permanent waters, but do redistribute into deeper pools and log jams in the main channel of streams in autumn (Brown and McMahon 1988; Tschaplinski and Hartman 1983). They may select alcoves and side channels of large rivers such as the Willamette River to rear instead of the main channel.(Andrus 1997). Small 1st order streams and tributaries are used (Skeesick 1970; Cederholm and Scarlett 1982; Brown and Hartman 1988). Groundwater channels may provide winter habitat (Sheng et al. 1990; Giannico 1995: Decker 1999). Riverine ponds (Peterson 1982a,b), beaver (*Castor canadensis*) ponds (Bryant et al. 1992; Nickelson et al. 1992), and lakes (Swales et al. 1988; Irvine and Johnston 1992; Minakawa and Kraft 1999; Johnston et al.

Table 1. Description of generalized salmon habitats located on a West Coast lowland floodplain (rain dominated). Adapted from Brown (1987).

Habitat Type	Water Level and Location	Substrate and Vegetation	Possible Fish Use
Permanent Water	Flowing or open standing water all year (ponds, lakes, rivers, terrace tributaries, and creeks	Variable substrate, dependent upon water velocities. Variable in aquatic and semi-aquatic vegetation, dependent on water velocities.	Salmonids all year. River (Murphy et al. 1989; Shirvell 1990). Lakes (Mason 1974; Johnston et al. 1987; Swain and Holtby 1989; Halupka et al. 2000)
Riverine and beaver ponds	May have water all year, but quality poor in summer.	Variable, usually a muck veneer, aquatic vegetation.	Winter rearing of coho/trout. (Peterson 1980, 1982a,b; Sabo et al 1999; Murphy et al. 1989; Elliott 1992).
Lake margins	Temporarily flooded fields and foreshore during winter freshets	Variable, substrates. Grasses, sedges, shrubs, Spiraea douglasii, willows.	Unknown in winter, (Mason 1974)
Ditches and channelized streams.	Variable (dry to flowing)	Mud and clay, uniform sides and bottom. Often re-colonized with sedges and rushes as ditch ages.	Coho and trout winter habitat. Access and water quality dependent. (Brown et al. 1999; Giannico 1995)
River sub-channels and alcoves	Water level and quality are variable Braided, capped, percolation, groundwater and overflow channels..	Sand and gravel substrate. No vegetation.	Use is water velocity dependent. Coho and trout all year, or winter only. (Burns et al. 1987; Sheng et al. 1990, Bustard and Narver 1975b; Mundie and Traber 1983).
Runoff Tributary	Small, steep if associated with valley walls, flow into larger rivers	Gravel and boulder substrate. No vegetation.	Steelhead dominate, coho and cutthroat. (Hartman and Gill 1968)
Estuaries, and Estuarine Drainages	Surface freshwater lens, summer. Small drainage, may flow only in winter, often tidal access	Variable substrate, but usually fines. Often salt tolerant sedges and grasses in upper estuary – estuarine drainages similar to intermittent tributary.	Coho (Tschaplinski 1987; Atagi 1994), Chinook (Healey 1979b).
Intermittent Tributary	Flow in winter, only isolated pools in summer. Often located in abandoned channels along valley walls. Wall based channels	Exposed sand /gravel pockets. Edges usually vegetated with; *Oenanthe sarmentosa, Scirpus microcarpus, Typha latifolia. Spiraea douglasii, Lysichiton americanum*	Coho and cutthroat in pools all year, rearing throughout in winter. (Peterson and Reid 1984; Cederholm and Scarlett 1982; Brown 1985,87; Franklin et al. 1982; Garrett 1998; Skeesick 1970)
Ephemeral Swamp	Dry in summer. Water levels adequate to support fish in winter. Located in abandoned channels.	Surface consists of organic muck blanket. Vegetation; *Oenanthe sarmentosa, Scirpus microcarpus, Typha latifolia, Zannichellia palustis, Lecidea* sp. *Spiraea douglasii, Lysichiton americanum*	Coho in winter, a few cutthroat trout may be present. Dry in summer (Brown 1985,87; Bustard and Narver 1975a) or spring fed (Cederholm and Scarlett 1991)
Seepage Site	Water at surface all year, Sites often located along valley walls. Often associated with yellow-orange precipitate.	Soil variable. Plant species include; *Juncus ensifolius*, *Sphagnum* sp., *Agrostis* sp.	Usually inadequate depth for fish. May provide water source. (Brown 1985;87)
Grass or Sedge Meadow	Flooded for limited periods in winter, dry in summer. Meadows often go dry before April. Water levels may be highly variable	Soil variable, often peat. Vegetation; *Carex obnupta*, 'grasses - *Aira* sp, *Agrostis* sp., herbs - *Gailum triflorum*, ferns - *Athyrium filix-femina*, Mosses - *Fontinalis antipyretica*, Sphagnum	Temporary. Fish may move across during floods. No winter rearing. (Brown 1985;1987)

1987; Swain and Holtby 1989; Mason 1974) are common over-wintering locations. Small swamps, wetlands, and sloughs may be occupied (Brown 1985; Peterson and Reid 1984; Cederholm and Scarlett 1982). In Black Creek, east coast of Vancouver Island, drainage ditches that were dry in summer contained winter rearing coho (Brown et al. 1999), as did ditches in the Salmon River near Langley, B.C. (Giannico 1995), and gravel pits in Alaska (Bryant 1988). All good over-wintering habitats have the common features of reduced water velocities, abundant cover (debris jams, fallen logs, root-wads, semi-emergent vegetation and undercut banks) and if groundwater fed will have warmer winter water temperatures (Decker 1999; Giannico 1995).

All species of salmon and trout use habitats found on coastal floodplains. All species of salmonids will spawn in braided side channels and groundwater channels of larger systems (Seng et al. 1991; Decker and Lightly in press; Bonnell 1991). In summer on the west coast of Vancouver Island, juvenile coho dominated low gradient (<2% slope) 2-3 order streams, cutthroat trout occupied higher gradient (>2% slope) 2^{nd} order streams, while juvenile steelhead were more numerous in low gradient (<3% slope) 3-4 order rivers (Brown et al. 1989). Hartman and Gill (1968) described differences in summer fish distribution in the Fraser Valley. Steelhead fry and parr resided in larger rivers and small steep tributaries that drained directly into a large river (run-off-tributaries). These systems would tend to have course substrates. Cutthroat trout were located in upstream tributaries, creeks less than 6-km in length, and small streams that drained through sloughs and swamps. Usually these drainages are wetted all year. Coho distribution did not extend far upstream into small tributaries, but coho juveniles used the more ephemeral watercourses. Coho salmon typically summer rear in pools found in small low gradient streams (Hartman 1965).

Juvenile coho may occupy estuarine habitats in autumn (Tschaplinski 1987; Atagi 1994) and may move into non-natal drainages and freshwater marshes in winter. Coho and trout have been documented to over-winter in coastal lakes (lacustrine habitats) and ponds (Irvine and Johnston 1992; Swales et al. 1988; Johnston et al. 1987). However, the role of flooding and freshets in making lake and estuary habitats available is not well documented. Coho salmon and cutthroat trout are closely associated with small watercourses and seasonally flooded lands located on coastal floodplains. I will concentrate on describing migration patterns and the types of floodplain habitats (riverine and palustrine) used by juvenile coho salmon and cutthroat trout during the winter.

Riverine and Palustrine Habitats

Coho salmon and cutthroat trout rearing habitat was characterized for one west coast floodplain (Brown 1985, 1987). Many of the smallest off-channel sites are pockets of water found within wall-based-channels (intermittent tributaries and ephemeral swamps). These channels are often associated with the lower floodplains of coastal rivers and may be well removed from the main channels (Franklin et al. 1982). These habitats are subject to degradation by human activities (agriculture, forestry, and urbanization) if not identified. Coho and trout over-wintering habitats, were readily identifiable during summer ground surveys based on characteristics, that included general location and topographic features, substrate type, vegetative association, vegetative stratum, and seasonal water table (Brown 1987). The "interpretative classification scheme" developed by Brown (1985, 1987) was applied to the winter flooded lands located on the early successional flood plain of Carnation Creek. Winter fish habitat and flooded lands are not the same, as winter habitat can be delineated from flooded lands (Brown 1987). A significant relationship was found between population size and area delineated as habitat for both coho salmon and cutthroat trout (Brown 1987).

Cutthroat trout and coho salmon migrate into seasonally flooded habitats in autumn although cutthroat trout migration tends to occur during late winter and spring (Hartman and Brown 1988; Garrett 1998). There are differences in the types of floodplain habitats use by the two species (Brown 1985). Cutthroat trout and coho salmon were associated with intermittent tributaries that had a noticeable flow all winter and had some water present though out the summer, often in the form of isolated pools. These channels could be recognised by the presence of exposed sand and gravel substrates. Coho salmon dominated sites dry in summer, but with standing water in winter (Figure 5). These sites were often densely vegetated with rushes and sedges and a "muck veneer" substrate (Canada Soil Survey Committee 1978) was a common feature. Thus, coho salmon juveniles used the most marginal (temporal) winter habitats associated with flooding and floodplains.

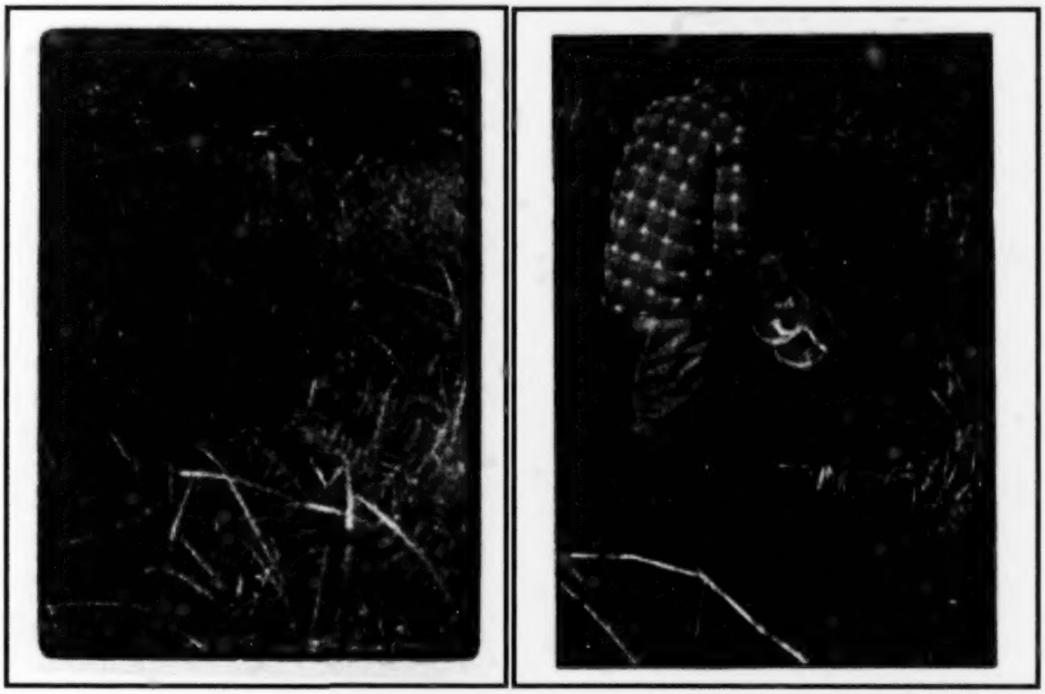


Figure 5. Ephemeral off-channel swamp located on the Carnation Creek floodplain a) summer and b) winter

The ratio of cutthroat trout to coho entering the off-channel sites decreased as the size and permanence of the sites decreased (Hartman and Brown 1988). Although few cutthroat trout entered the most marginal sites, they were more diverse in size and age than coho in the intermittent tributaries. These differences in the winter use of very small seasonal floodplain drainages may represent an example of resource partitioning between winter rearing populations of coastal cutthroat trout and juvenile coho salmon. This resource partitioning has been described for summer rearing populations of coho and trout (Glova 1978, 1984; Hartman 1965).

Ecology and Response to Freshets

During the summer, juvenile coho reside in pools and side-channels of coastal streams (Hartman 1965; Brown and McMahon 1988; Bryant et al. 1992). They are highly visible and are often exposed in mid to upper water positions (Dolloff and Reeves 1990). They feed on drift and aerial drop (Nielsen 1992). "Small-scale habitat movements" have been noted for juvenile salmonids in coastal streams during the summer (Kahler et al. 2001). Upstream movement predominated and 28-60% of the juveniles moved at least one habitat unit. This movement may be associated with habitat choice as juvenile salmonids moved from shallower to deeper pools. Summer movement is not as extensive or as dramatic as autumn redistribution.

The first storms in autumn appear to trigger the autumn redistribution from summer rearing sites to over-wintering habitats (Brown 1985; Peterson and Reid 1984; Bilby and Bisson 1987). Juvenile coho moved from the exposed main channel pools into either debris jams or into flooded swamps and minor intermittent tributaries located on the floodplain (Bustard and Narver 1975a; Skeesick 1970; Mason 1976; Peterson 1980; Cederholm and Scarlett 1982; Tshaplinski and Hartman 1983; Jenks 1989; Shirvell 1990). Coho populations peaked in the off-channel sites within two weeks of the first fall storms and declined gradually until out-migration the following spring (Figure 6). Later storms, even though greater in magnitude than the initial fall freshets, elicited no further increase in juvenile coho numbers in the ephemeral swamp. A similar relationship between river discharge and fish off-channel movement into riverine ponds was noted for the Clearwater River (Cederholm and Scarlett 1982). Bell et al. (2001) reported that juvenile coho salmon occupying alcove habitat in Prairie Creek, California, had higher densities and higher fidelity following a November flood than did those rearing in backwaters or main-channel pools. They noted that marked juvenile coho displacement was greatest on the first peak discharge, although it was also the highest discharge recorded for that winter. Controlled flow experiments have also indicated that increased water discharge can trigger the downstream movement of coho (Giannico 1995; Giannico and Healey 1998; McMahon and Hartman 1989).

The source of juvenile coho entering off-stream floodplain sites is strongly dependent upon their summer rearing location. The majority of off-channel immigrants originate from main-channel locations up-stream (Cederholm and Scarlett 1982). Peterson (1980, 1982a,b) documented the autumn downstream movement of juvenile coho into "riverine ponds" in the Clearwater River Washington and recorded downstream movements of 38 km. In winter in

Carnation Creek, juvenile coho were preferentially captured in the off-channel site that bordered their main-channel summer marking locations (Brown 1985).

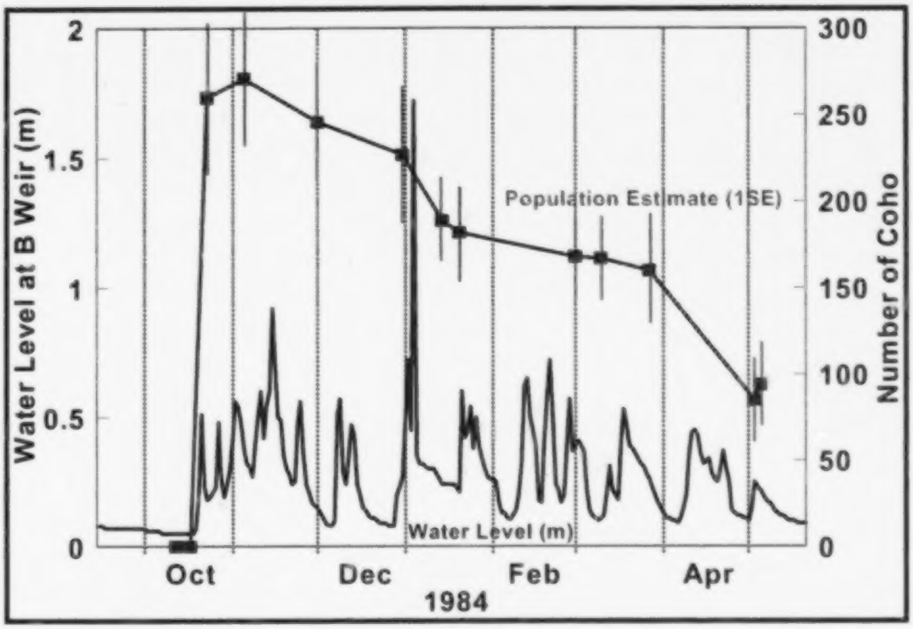


Figure 6. Population estimates of over-wintering juvenile coho salmon within an off-channel site located on the Carnation Creek floodplain. Adapted from Brown and McMahon (1988).

The magnitude of the first fall freshets established the degree of access to floodplain sites and governed the number of coho which entered these sites (Brown and Hartman 1988). Brown and Hartman (1988) estimated that 10% of the juvenile coho rearing in the main channel of Carnation Creek during the summer moved into floodplain over-wintering habitat in autumn. Brown (1985) described fish movement during the first fall storms as either passive (across the flood plain with the flow) or active (up through the outlets into the swamps and minor drainages). The relative proportion of active and passive movement is unknown.

In coastal watersheds, considerable downstream redistribution from the upper portions of a watershed to the lower portions occurs in autumn. In Black Creek 71% of the coho juveniles reared in the upper half of the watershed in summer, while 75% of the smolts originated from the lower half of the watershed the following spring (Brown et al. 1999). The lower portion of the watershed had limited summer rearing due to a lack of water and poor water quality. A similar autumn redistribution of coho from the middle reaches of the Salmon River (Langley) to the lower reaches and lower ditches of the watershed was noted by Giannico (1995). He described the lower reaches as "suboptimal to unsuitable" summer habitat (due to high water temperatures). The lower reaches of the glacial Taku River provided essential rearing habitat for juvenile salmon spawned upriver (Murphy et al. 1997). The autumn-winter juvenile coho movements recorded by Bell et al. (2001) may have been due to a similar downstream over-wintering relocation. Their out-migrant traps were placed high in the watershed. Not all watersheds show this response. In Southeast Alaska, although microhabitats changed, within permanently wetted sites no apparent major redistribution of juvenile coho within the watershed was observed in the autumn (Dolloff 1987).

The movement of juvenile coho in autumn is a permanent shift to winter habitat rather than a temporary redistribution of juveniles with the floodwaters, lasting only for the duration of the freshet. It appears that once juvenile coho have moved into a specific site following the first autumn freshets (e.g. under a log in an ephemeral swamp) they remain there until emigration in spring. Brown (1985) found that 67% of the juvenile coho that were uniquely marked in autumn (immediately after movement off-channel) were present at the same site in March. When uniquely marked fish were recaptured, 80% were found within 10 m of their original making site. This indicates considerable fidelity to a specific winter habitat site by juvenile coho. Giannico (1995) observed that fewer coho juveniles tried to leave experimental channels as water temperature decreased. Thus, over-wintering coho may be reluctant to move in mid-winter when water temperatures are low.

The behaviour of juvenile coho during autumn migration influenced their eventual over-wintering location. A small (1 km long) tributary located on the Carnation Creek floodplain was composed of a lower intermittent section (isolated pools of water in summer) and an upper ephemeral section that was dry in summer (Brown 1985). In late summer, juvenile coho residing within the isolated pools of the lower intermittent section were marked. In autumn during the first freshets, coho migrating from the main-channel through a small fence at the mouth of the tributary were also marked. The majority of resident coho (marked in the intermittent section during September) remained in this lower section, while after autumn redistribution migrants (from the main-channel) comprised 78% of the coho population in the upper ephemeral section and 44% in the lower intermittent section.

It was suggested that the autumn freshets represented a period of movement and relocation for cutthroat trout that was similar to that recorded for coho (Tshaplinski and Hartman 1983). However, the annual pattern of trout entry and exit from off-channel sites differed from that of coho. In late winter and early spring the direction of trout movement was less consistent than for coho (Hartman and Brown 1988). Fish that appeared to be the same individuals (based on size) were noted to move upstream and back downstream within a span of a few days. Trout in spawning condition entered and left the larger intermittent tributaries in spring (March-May). Cutthroat trout movement within Musqueam Creek (Vancouver, B.C.) was also very limited in winter (Heggenes et al.1991b). Only 18% of the marked trout moved > 50-m, 48% remained within 3-m, and 32% were recaptured within 1-m of their original capture site.

It is possible that behavioural differences in response to freshets may dictate the types of winter habitats eventually used by coho and cutthroat trout. Juvenile coho have a tendency to remain higher in the water column as water levels rise than cutthroat trout (Bustard and Narver 1975b). It is possible that juvenile coho move laterally onto the flooded margins of a stream and are more likely to enter flooded sites than trout that are more likely to remain in the stream channel. The behaviours that facilitate the movement of juvenile coho into seasonally flooded sites may also promote stranding of juvenile coho. Trout are more closely associated with rubble substrate (Bustard and Narver 1975b, Osborn 1981) and may seek refuge from freshets in that rubble within the main channel. In winter larger trout (>9cm) exhibited strong preferences for depths > 25cm and for sites with > 40% overhead cover (Heggenes et al. 1991a). Coastal cutthroat trout adults shift microhabitats (e.g. move into woody debris accumulations or move downstream into secondary channels) but do not move extensively in response to a bank-full flood (Harvey et al. 1999). The overwinter survival of adult and sub-adult cutthroat trout, appeared to be related to winter temperature and flow regimes in the stream (Michael 1989).

Numerous authors have related gravel scour caused by floods to the loss of salmon eggs and mortality of alevins (Lapointe et al 2000). In Mill Creek, Califorina, floods caused high mortality to chinook eggs (Gangmark and Bakkala 1960 cited by Healey 1991). The high mortality was due to a loss of eggs washed out of the gravel and by reduced percolation rates following silt deposition. Wickett (1959) reported that a flood on January 1958 had caused considerable streambed scouring to the Qualicum River, B.C.. This had resulted in high mortality of incubating chum and coho salmon eggs and alevins. After the flood coho and chum eggs were found along the banks and in the bushes of the lower river. Stream-flow levels during incubation and the severity of winter conditions influence pink salmon embryo development (Heard 1991). Sandercock (1991) felt that winter flooding, with the disruptive effects of gravel movement, accounted for a high proportion of coho egg and alevin loss.

The impact of winter floods on salmonids rearing in coastal streams may not be as severe as we once envisioned. Although high discharge from egg deposition to the first week after emergence can cause considerable mortality, high discharge during later stages seemed to be of minor importance to juvenile Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) survival (Jensen and Johnsen 1999). De Leeuw (1982) examined the effects of two winter flood events on juvenile salmonids and associated rearing habitat in the Salmon River (Langley) and concluded that only minor changes took place as a result of the highest instantaneous discharge on record for that river. Irvine (1986) concluded that during natural migratory periods, there is a positive relationship between fry leaving a stream and flow fluctuations. However, he found that varying discharge had little effect on older rainbow trout (Irvine 1987). Dewberry et al. (1998) described the immediate effects of floods on Pacific salmon in "healthy watersheds" as being minimal or short-lived and in the long term floods should have positive effects. A devastating 1974 flood that washed out rail lines, roads, houses and bridges along the Skeena River in northern British Columbia did little damage to the salmon fishery in later years (Roberts 1979).

Brown (1985) noted that the ability of juvenile coho to remain within a given site appeared dependent upon specific characteristics of the site (e.g. flooding patterns). The displacement of marked fish from floodplain habitats was examined following the largest freshet ever recorded at Carnation Creek (63 m^3/sec on Jan 4/84). Sites within side-channels that were subject to higher velocity waters had 45%, 46%, and 69% of the population replaced. More protected off-channel sites (not subjected to direct main-channel flows) had 10%, 18%, and 22% of the juvenile coho population exchanged on the same freshet. Juvenile fish habitat in low gradient floodplain streams appears to be very resilient to extreme flood events.

Stranding and Survival Off-channel

The relationships between coastal floodplains, flooding and stranding of salmon juveniles have never been studied in a formal way. This may be due to the extreme difficulty of working under flood conditions in winter, of finding stranded fish in terrestrial environments, and in designing controlled experiments prior to unpredictable flood events. Juvenile fish in autumn must enter and occupy sites that remain viable habitats until spring. How they select these sites is unknown. In spring they must successfully emigrate from these sites. Two factors that influence their likelihood of returning to the main channel in spring are; the weather in April-May and the morphology of the site.

Juvenile coho and trout can become stranded within small man-made and natural depressions on a floodplain following a freshet. These sites are only temporarily wetted and are not suitable as over-wintering habitat. In 1986 following an October freshet, 6 juvenile coho were observed in 2 small (2 m diameter by 1 m deep) soil pits dug on the Carnation Creek floodplain. These soil pits went dry within a week of the freshet and the coho perished. I have also noted coho juveniles in natural shallow pools of water within drying side channels. These pools (located in porous gravel substrate) would dry within days and the juvenile coho would perish. Bell et al. (2001) captured juvenile coho (initially tagged in the main channel) on the floodplain during a mid-winter "overbankfull" discharge. A large juvenile rainbow trout was found in an unconnected natural shallow pool in the middle of the treed floodplain bordering Shaw Creek on Vancouver Island (J. Hillier, personal communication).

The stimulus to emigrate from the off-channel sites could be related to either water level or temperature. Adequate water levels are critical for the emigration of coho from the off-channel sites during March to May (Brown 1985). Juvenile coho move during periods of higher water but not necessarily during the highest flows. Water temperatures in off-channel sites are slightly warmer than in the main stream through the winter and spring (Scrivener and Brown 1993; Holtby 1989) and removal of riparian vegetation may further increase temperatures. There does appear to be a strong inverse correlation between water temperature in late spring and median emigration time from an off-channel site (Holtby and Baillie 1989). The warmer the spring the earlier the juveniles moved back to the main channel. However, warm spring temperatures are also associated with periods of reduced rainfall, lower water levels, and stranding (Brown and Hartman 1988). In Carnation Creek, coho emigrating from the off-channel sites were primarily parr and they did not show the degree of silvering associated with coho smolts emigrating from the lower river (McMahon and Hartman 1988). Thus, juvenile development (smoltification) is not a clear reason for emigration from off-channel sites back to the main channel.

Annual winter survival of juvenile coho in a given site is variable. Survival rates of 71% (Bustard and Narver 1975a), 67% (Tschaplinski and Hartman 1983), and 32% to 51% minimum (Brown 1985) have been reported for the same Carnation Creek site during different years. Quinn and Peterson (1996) estimated survival rates of wild coho (individually marked in October) from Big Beef Creek, Washington for two years at 25% and 46%.

Brown and Hartman (1988) examined the contribution of floodplain sites to a watersheds total coho smolt output for a dry and a wet spring. The seasonally flooded sites contributed 15% during a dry spring and 23% during a wet spring. April-May water levels were 37% below the 13 year mean water level during the dry spring (1983) and 55% above during the wet spring (1984). Stranding of juveniles was noted in spring 1983, but not in spring 1984. They speculated that the inability of coho salmon smolts to emigrate from off-channel habitats (stranding) during a dry spring may have reduced the off-channel contribution for that year. It thus appears, considerable differences in annual climatic conditions can influence off-channel survival.

Site morphometry may be responsible for differences in winter survival as survival rates vary between sites within a year. In the Clearwater River, Washington, Peterson (1982b) estimated survival rates from two ponds at 28% and 78% and Cederholm et al. (1988) estimated survival rates for two Clearwater River sites at 0 and 80%. At Carnation Creek, survival rates ranged from 44% to 76% for 6 different ephemeral sites during 1984 (Brown (1985). It thus appears that variation in survival is due in part to site differences.

The relationship between the physical characteristics of an off-channel site and survival of fish rearing in them was examined in the Clearwater River (Cederholm et al. 1988; Peterson 1982b). Peterson (1982b) postulated that survival and growth differences were related to pond morphometry, predation effects, and times of immigration. The physical dimensions of an off-channel site were considered important attributes in providing favourable winter rearing conditions. Shallow ponds that were prone to de-watering and subject to avian predation yielded the lowest survival rates. Creation of deeper pools (blasting) and raising the water level (small dam) improved survival rates from 11% to 56% (Cederholm et al. 1988). In the Clearwater River, Cederholm and Peterson (1988) reported that prior to enhancement, one site (Swamp Creek Channel) would go dry each winter killing all of the coho immigrants.

In the Clearwater River, Washington, bird predation rates for two different off-channel ponds were studied (Zarnowitz and Raedeke 1984). One pond was large (1.3-ha) and shallow (<1.3-m) and the other was smaller (0.85-ha and deeper (< 3.5-m). The most active predators on coho juveniles were the pied-billed grebe and belted kingfisher. The belted kingfisher captured > 93% of its prey within depths < 0.6-m, while the pied-billed greebe took some prey in deeper areas of the ponds. Great blue herons, hooded mergansers and otters also preyed on juvenile salmonids. Total predation on coho salmon in the shallow pond was nearly double that recorded in the deeper pond. Thus, pond depth and size appear to be important aspects in reducing avian predation.

Growth and Size

There is considerable evidence that over-winter survival of juvenile coho is autumn size dependent (Holtby 1988, Hunt 1969, Quinn and Peterson 1996). Autumn size frequency distributions differ from spring distributions (Irvine and Johnston 1992, Lindroth 1965, Oliver and Holeton 1979, Thedinga et al. 1989, Toneys and Coble 1980, West and Larkin 1987). This has been attributed to size dependent over-winter survival and emigration. It is possible that smaller fish have higher weight-specific maintenance requirements and lower energy storage, thus starvation rates are higher for smaller fish (Cunjak 1988a,b). Also, predation rates on smaller fish may be higher (Healey 1982; Post and Evans 1989). It is also possible the smaller fish may take more risks then larger fish (size dependent behavioural tactics). Larger individuals may need more energy during winter and exhaust body reserves (Elwood and Waters 1969). This could initiate early salmonid migration of larger individuals (Riddel and Leggett 1981).

Off-channel habitats have been described as refuge habitats to buffer the impact of severe winter storms (Cederholm and Scarlett 1982) and the movement of juvenile fish in autumn to over-winter within seasonal habitats has been considered a behaviour designed to avoid unfavourable main channel winter conditions (Skeesick 1970). However, for juvenile salmon there may be a survival advantage of obtaining a threshold size when entering marine environments (Henderson and Cass 1991; Holtby et al. 1990; Nicieza and Brana 1993; Ward and Slaney 1988; Ward et al. 1989). Juveniles may adopt size dependent behavioural tactics that allow for attainment of best growth conditions through winter and spring relative to risk of stranding. Size dependent behavioural tactics relative to feeding and predation have been studied in summer rearing salmonids (Dill 1983, Martel 1996, Walters and Juanes 1993) and for Atlantic salmon in winter (Metcalfe et al. 1986). Size dependent behavioural tactics have not been clearly demonstrated for off-channel winter habitats in coastal watersheds. Movement off-channel may be an opportunity for smaller coho juveniles to grow faster than main-channel rearing individuals. In Carnation Creek, following coho redistribution in autumn, each off-channel site had a distinct size distribution and population mean size (Brown 1985). There was a trend (not significant) towards smaller individuals (marked in November) remaining in off-channel habitat until April-May, while larger individuals disappeared, possibly emigrating earlier than the smaller fish.

In coastal watersheds salmonid activity does not cease with the onset of the winter period. Coho have been observed actively feeding at temperatures below 2.5°C (Bustard and Narver 1975a) and below 4.0°C (Giannico and Healey 1998). In the Clearwater River, juvenile coho continued to feed throughout the winter months (Friesen 1990). Rainbow trout have been observed feeding in super-cooled water (Needham and Jones 1959) and have been caught on bait at 0°C (Maciolek and Needham 1952). Coho juveniles and cutthroat trout have been captured in baited traps at water temperatures below 1°C (Brown 1985). Giannico (1995) observed coho feeding at 3.0°C and confirmed this observation with stomach content analysis. However, he reported that growth was slight and condition factor decreased from January to March. It is possible that salmon juveniles have a reduced ability to assimilate ingested foods at lower temperatures (Cunjak and Power 1987). There is evidence that juvenile salmonids avoid light in winter and are active at night (Cunjak 1988a).

Researchers studying floodplain habitats ((Skeesick 1970; Bustard and Narver 1975a; Peterson 1982a,b) have observed an increase in mean fork length from the time of autumn immigration until spring emigration. The mean fork-length of juvenile coho within an ephemeral swamp located on the Carnation Creek floodplain, increased 22 mm from October 24th to May 5th (0.17 mm/day, Brown 1985). The highest growth rates were in April and May. Growth of individual fish was responsible for this increase and size dependent mortality or migration did not contribute. Growth in the more placid ephemeral swamps is higher than in the main-channel. In Carnation Creek, the fork-length growth of individually marked juvenile coho from November 10th until March 10th 1984, was 9.4 mm (95%CI ± 0.8 mm) in ephemeral swamps, averaged 6.7 mm (95%CI ± 0.1) in intermittent tributaries, and was 3.8 mm in the one main channel site examined (Brown 1985). A similar experiment conducted in 1985-86 at Carnation Creek, that also used individually marked coho, recorded growth rates from November 15th to April 5th of 17.6 mm (95%CI ± 1.8 mm) for three ephemeral swamps and 10.2 mm (95%CI ± 0.9 mm) for three main-stream sites. Approximately 80% of the fork-length growth occurred during the last 70 days. In 1995 and 1996 the spring-growth (weight change) of individually marked coho was measured in a seasonally flooded wetland at Sayer Creek a tributary of Black Creek (Figure 7). The largest increase in mass occurred prior to spring emigration. Juvenile coho more than doubled in weight during their last 100 days of rearing.

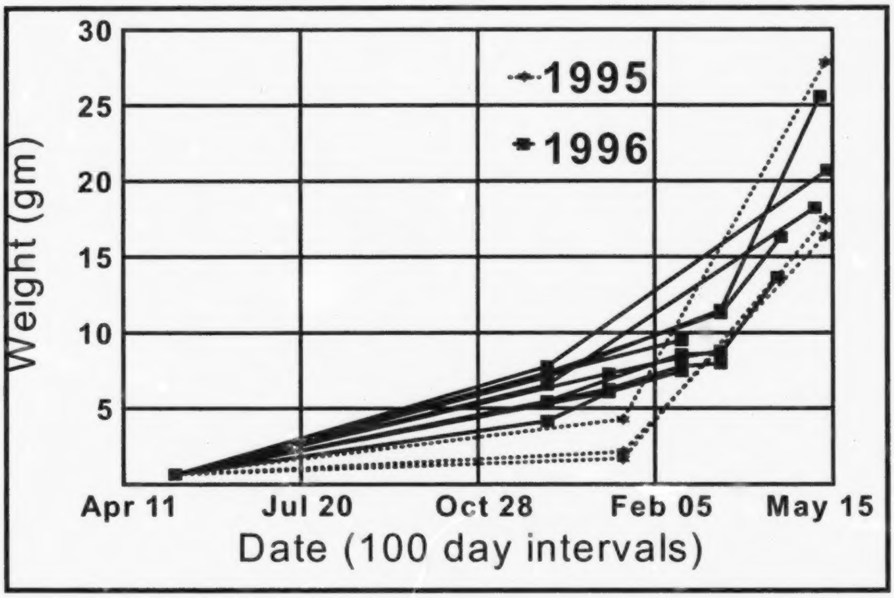


Figure 7. Growth of individually marked juvenile coho, recaptured over two years from flooded lands located at Black Creek, Vancouver Island.

Bradford et al. (1997) noted that longer streams in broader floodplains produced the largest smolts. He speculated that the low-gradient (floodplain habitats) had higher water temperatures, more off-channel habitat, and a longer growing season than high-gradient streams. In the Fraser River main-stem, mean length of juvenile chinook decreased with distance upstream (ranged from 97 mm at km 110 to 65 mm at km 770; Levings and Lauzier 1991). We have noted a similar relationship between the distance upstream and October size of juvenile coho in the main channel of Black Creek (Figure 8). The size of the smolts produced from the various tributaries of Black Creek may also be related to agricultural activities. It is likely winter-spring growth is influenced by nutrient inputs associated with dairy farms and by warmer spring waters due to removal of riparian cover along stream/field margins within each of the basins (Figure 9).

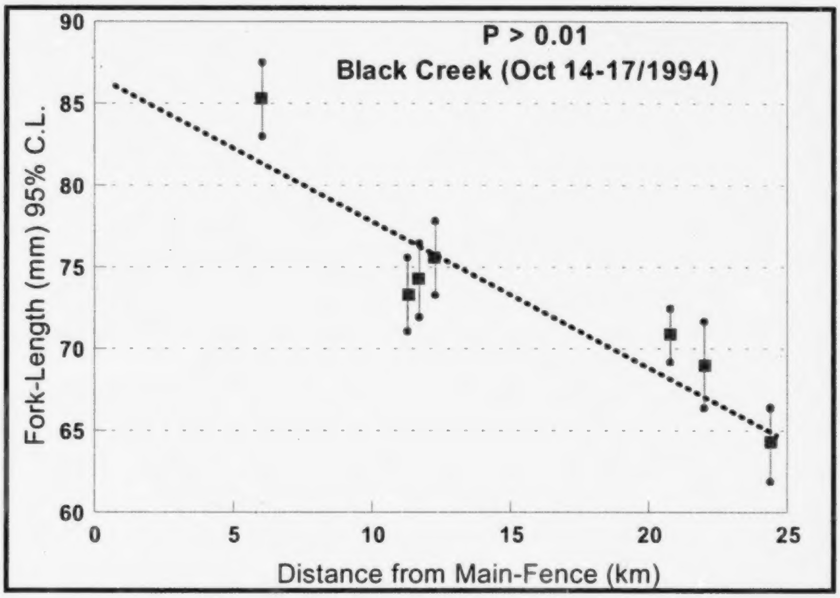


Figure 8. Juvenile coho population mean size in October at 7 Black Creek main-channel sites. Size of coho decreases as distance from the ocean increases.

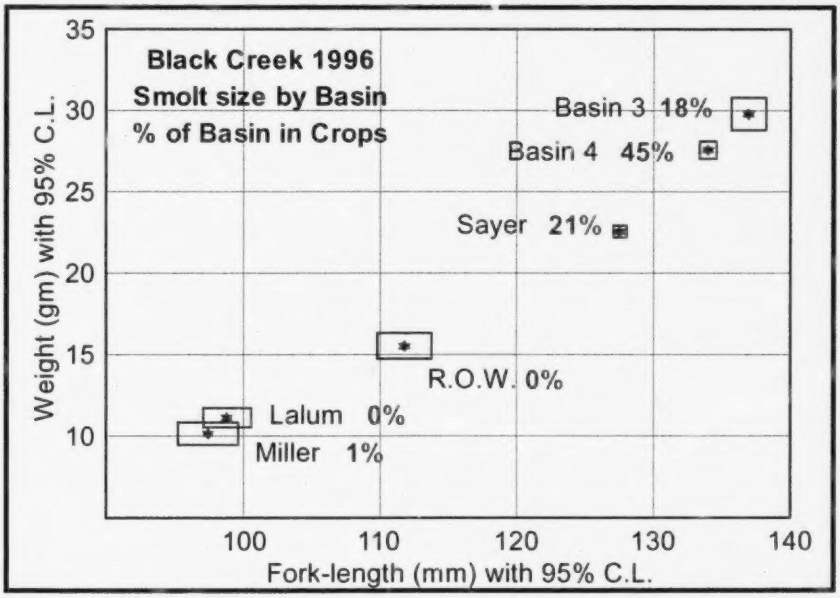


Figure 9. Coho smolt size from six Black Creek tributaries. Percentage of basin area cleared for crops is given for each basin.

Invertebrates and Nutrients

Invertebrates are important in aquatic ecosystems as they influence functional processes such as decomposition and when eaten link primary producers with fish (Rader 1997). Juvenile salmon growth is dependent upon the availability of invertebrates as food. We might expect considerable differences in availability of invertebrates as fish food during different seasons. In summer coho mainly fed on drift invertebrates or on aerial drop (Hartman 1965; Nielsen 1992; Rader 1997: Mundie 1974). Coho salmon form dominance hierarchies and fed mostly on drifting invertebrates (81%, Nielsen 1992). These types of food items may not be available in winter. We also expect differences in invertebrate communities when comparing flowing stream habitats to seasonally flooded wetlands. Terrestrial insect inputs (aerial drop) and benthic drift are greatly reduced and off-channel sites lack a directional flow for much of the winter and spring. The methods of feeding, types of invertebrates, and abundance of food organisms differ between off-channel and main channel habitats during winter. Coastal invertebrate species must have strategies that enable them to survive winter freshets and exploit seasonally wetted off-channel habitats.

On coastal floodplains the months of greatest litter-fall are September to November (Neaves 1978; Holtby 1989). In flowing coastal streams the timing and magnitude of detritial inputs (just prior to autumn storms), results in high winter export and low retention of litter materials (Richardson 1994; Kiski et al. 1999). Off-channel sites form an important holding and conditioning location for leaf litter such as red alder (*Alnus rubra*). Also, considerable organic material has collected within the off-channel sites on the floodplain during the dry months. Red alder leaves are consumed by invertebrate shredders at much higher rates if they have been subjected to > 30 days of microbial conditioning in wetted sites (Triska et al. 1982). It appears two microbial process (cellulose decomposition and hydrolytic activity) are different in floodplain habits versus main channel interstitial sites (Claret et al. 2001). The first invertebrates to appear in temporary waters in autumn-winter are herbivorous in nature (Abell 1956 cited by Williams and Hynes 1976) and could utilize this supply of organic materials. Salmon carcasses can also supply considerable nutrients to a watershed (Cederholm et al. 1989, 1999). Small off-channel depressions may trap salmon carcasses, give time for their decay, and allow derived nutrients to be absorbed. The spatial distribution of such marine-derived nitrogen is determined by flooding and by the activity patterns of piscivorous predators (Ben-David et al. 1998).

Invertebrates that occupy and exploit seasonally wetted off-channel sites have adaptive mechanisms for coping with summer drought. Invertebrates that are capable of surviving in seasonal off-channel sites must either remain dormant within the site during the summer, retreat to more permanent waters in spring, or exploit other environments during summer. Williams and Hynes (1976) divided the fauna of temporary streams into three groups:

1) autumn-winter fauna (successfully reproduced before sites stopped flowing in spring),
2) spring fauna (reproduce when shallow pools are left),
3) summer fauna (terrestrial, move onto dry substrate).

Scrivener and Carruthers (1989) compared benthic macroinvertebrate populations in the main-channel of Carnation Creek and four off-channel swamp sites. At each of the off-channel sites both emergent vegetation and bare-mud (nonvegetated) samples were taken. Benthic invertebrate densities were 7-10 times less in the main-channel in winter than in summer. There was no significant difference in invertebrate numbers in the off-channel and main channel sites. Main channel benthic densities ranged from 365 to $1000/m^2$ in winter (interpreted from graphs; Scrivener and Carruthers 1989) while off-channel vegetated sites ranged from 200 to $1000/m^2$. In off-channel sites a greater density of invertebrates (4 to 10 times more) were found at sites with rooted vegetation than at bare-mud sites. All sites were located on the Carnation Creek floodplain and these off-channel sites corresponded to those containing over-wintering populations of juvenile coho (Brown 1985,1987).

Different communities of organisms existed within the swamps and main channel (Scrivener and Carruthers 1989). In the main channel, organisms adapted to living in fast flowing water dominated the community (mayflies, stoneflies and dipteran larvae; Culp and Davies 1983). In the main channel, Scrivener and Carruthers (1989) found, mayflies such as; *Cinygmula* sp., *Epeorus* sp., stoneflies such as; *Alloperla*, *Capnia*, *Kathroperla*, and *Nemoura*; and Dipterans represented by midges (chironnomids of subfamilies Tanypodinae and Orthocladinae). Potential fish-food organisms in the off-channel sites consisted of dipteran larvae, copepods, ostracods, mayflies, amphipods, and caddisflies (Scrivener and Carruthers 1989). Mayflies such as *Ameletus* sp and *Paraleptophlebia* sp were common at sites with rooted vegetation while dipteran larvae (midges and biting-midges (Ceratopogonids and Simulids) were more common on exposed substrate.

Juvenile coho are opportunistic feeders, feeding on whatever invertebrates are present. In winter, aquatic larval forms of organisms dominate the diet of off-channel rearing juvenile coho, accounting for more than 99% of the identifiable gut weight (Friesen 1990). In Clearwater off-channel pond habitats, Peterson (1980, 1982b) had identified Chironomidae as the most important prey item, while Baetidae nymphs and Limnephilidae larvae were also important prey items. Peterson (1982b) noted that adult chironomids were more important than larvae in one shallow pond.

In the Clearwater River watershed, Friesen (1990) compared the winter diets of juvenile coho residing in a permanent 0.5 ha pond (similar natural ponds described by Peterson 1980, 1982b) and six constructed ephemeral ponds described as "a beaded channel" by Cederholm and Peterson (1989) and Cederholm and Scarlett (1991). Friesen (1990) found that an isopod (*Asellus* sp) represented 59% of the total gut contents by weight (76% of identifiable gut contents) in the pond. The highest percentage of isopods were recorded in December (80%) and the lowest in March (36%). In contrast *Asellus* sp represented < 1.5% of the gut contents by weight in the beaded channel. In the beaded channel a variety of invertebrates were consumed. Chironomidae (larvae and pupae), Oligochaetes, copepods, and Limnephilidae (caddisfly larvae) were dominant prey taxa (44% of total diet). Limnephilidae were not present in the gut contents until spring (Friesen 1990).

High rainfall and flooding can play an important role in making invertebrate food available for juvenile coho salmon in both off-channel and creek habitats in late fall and early winter. Sediment saltation has the potential to disturb benthic organisms (cause drift) early in the storm hydrograph (Culp et al. 1986). In Pudding Creek, California, coho salmon diets were less diverse and had a larger component of terrestrial invertebrates than steelhead juveniles (Pert 1993). However, during periods of high stream flow organisms such as earthworms and terrestrial adults were the predominant food items of steelhead. Flooding appeared to allow juvenile salmonids access to a wider range of food resources and winter floods may be important for supplying invertebrate food and sustaining fish growth and condition. Pert (1993) also noted that fish collected from inundated vegetation on floodplains had high stomach fullness. In Convict Creek, California trout feeding appeared to be associated with flood events (Maciolek and Needham 1952). In Baker Creek, Bellingham, Washington, terrestrial springtails comprised > 70% of the coho food in December following a heavy rain (Minakawa and Kraft 1999). In January the same fish fed more on benthic invertebrates (taeniopterygid nymphs, simulid larvae, and chironomid larvae). Conversely in Carnation Creek, annual benthic invertebrate densities were lowest when winter freshets were frequent and the lowest main-channel benthic invertebrate density was recorded 10 days after an extreme freshet (Scrivener and Carruthers 1989). Elwood and Waters (1969) suggested that extreme freshets in small streams could reduce both fish and invertebrate densities through scouring of habitat. This reduction is generally short-lived as a reserve of invertebrates exists deep in the substratum of a stream (Williams and Hynes, 1974). It appears that the first major increase in flow elicits the largest increase in invertebrate drift and the increase is less with each successive flow increase (Irvine 1985).

Relative Importance of Off-channel Floodplain Habitats

Off-channel winter habitat is important in terms of coho smolt production. The amount of off-channel habitat available for coho rearing explains in part a watersheds ability to produce coho smolts (Sharma and Hillborn 2001). Peterson and Reid (1984) estimated that 20-25% of the Clearwater River's coho smolts had over-wintered in off-channel habitats. Lestelle et al. (1993) estimated that 30% of the Queets River coho reared in off-channel ponds. In Carnation Creek, for the two years estimated, a minimum of 23% and 15% of the watershed's coho smolts came from natural ephemeral and intermittent sites located on the floodplain (Brown 1985). Off-channel winter habitat that was totally devoid of standing water in summer, accounted for more than 15% of Carnation Creek's total smolt output in 1984 (Brown and Hartman 1988).

Marshall and Britton (1990) found a relationship between accessible stream length and coho escapement. This relationship was re-examined by Bradford et al. (1977). They reported that the accessible portion of Pacific coastal streams (fully seeded) can be expected to produce approximately 1,500 coho smolts/km (Bradford et al. 1997). Cederholm and Reid (1987) compiled data from eight studies and estimated an average coho biomass of 1.8 g/m^2 for Pacific Northwest streams.

The densities of coho, utilizing off-channel overwintering sites, is highly variable depending on site characteristics and methods of measuring surface area. Scarlett and Cederholm (1984) estimated the August-September coho densities in four small tributaries of the Clearwater River to be; 1.01, 0.28, 0.19, and 0.26 coho/m^2. In late winter, an average density of 0.32 coho/m^2 was measured in the natural off-channel sites located on Carnation Creek (Brown 1987). This estimate is not an estimate of density relative to wetted surface area as it includes small hummocks. The number of coho immigrants from Paradise Pond (a 0.5 ha site located on the Clearwater River, Washington) increased from 0.64 coho/m^2 to 0.84 coho/m^2 following the blasting of deeper pockets of water (Cederholm and Peterson 1989). An ephemeral tributary that went dry in winter supported approximately 2.9 coho/m^2 (mean of 884 coho) after the blasting of six pools established a permanent 300 m^2 of winter rearing habitat (Clearwater River beaded channel, Cederholm and Peterson 1988).

Groundwater fed side-channels, constructed in B.C., usually contain water year around and provide spawning, summer rearing and winter rearing habitats. In this respect they differ from many of the natural floodplain habitats that are seasonal and used only for winter rearing. The contribution of constructed off-channel sites is proportional to the accessible length of the drainage, relative size of the constructed habitats, and the availability of natural off-channel rearing sites. A constructed side channel contributed 62% of the total smolt production of Nile Creek, a relatively small creek on the eastside of Vancouver Island (M. Sheng, personal communication). Off-channel habitat constructed on the Vancouver River, a larger system (18-23 km accessible) that lacked natural off-channel habitat, yielded 76% of the watersheds coho smolt production in spring of 2002 (Bates 2002). These constructed off-channel sites produced 0.71smolts/m^2. In the Cheakamus River and Coquitlam Rivers (B.C), constructed off-channel sites contributed an average of 46% of each watersheds total smolt production (Decker and Lightly, in press). Coho smolts densities for three constructed side-channels of the Oyster River, B.C. were 0.39, 1.32, and 0.4 coho/m^2 (Decker and Lightly, in press). The average winter density of 0.69 coho/m^2 for the side channels was 2.3 times higher than in the main river channel. Juvenile coho smolt densities from two west coast Vancouver Island constructed side-channels produced 0.44 smolts/m^2 (Klanawa River) and 0.48 smolts/m^2 (Sarita River) in spring of 2002 (M. Sheng, personal communication).

Placid ephemeral swamps and constructed side-channels can provide higher quality juvenile coho over-wintering habitat than main-channels, with higher winter growth rates, higher densities and possibly higher survival rates (Tshaplinski and Hartman 1983; Bustard and Narver 1975a). Off-channel habitats provide juvenile coho salmon with an alternative to rearing within the main channel during winter and may buffer smolt output from a watershed. This alternate strategy may provide juvenile coho with a survival advantage under specific climatic conditions (Brown and Hartman 1988).

Requirements

Hartman and Brown (1988) listed the requirements necessary for successful utilization of coastal floodplain winter habitat by juvenile coho salmon and cutthroat trout. These include:

1. Access to off-channel habitat during the first autumn storms must be readily available.
2. Winter water level must be adequate to maintain the population from October to May.
3. Refuge (woody debris or aquatic vegetation) must be present to reduce predation and provide protection during extreme winter floods.
4. Levels of dissolved O_2 must be high and concentrations of H_2S and suspended sediment must remain low.
5. Juvenile salmonids feed and grow during the winter and spring, thus trophic pathways must be maintained.
6. Access, from off-channel sites to the main channel must be available before warm dry spring weather begins (May).

Estuary Habitat (Rain-dominated)

In the Pacific Northwest, juvenile coho have been documented using estuarine habitats for summer rearing. Estuaries that have been studied include; Carnation Creek (Tshaplinski 1982,1987,1988), Courtenay River (Bravender et al. 2002), Salmon River on Northern Vancouver Island (Atagi 1994), Englishman River (Bravender et al. 1997), Squamish River (Ryall and Levings 1987), Campbell River (Raymond et al.1985), Somass River (Birtwell et al. 1984), Sashin Creek, Alaska (Crone and Bond 1976), and Porcupine Creek, Alaska (Thedinga and Koski 1984). The volume of freshwater entering these estuaries varies seasonally and is rain dependent. Coastal lowland estuaries exhibit high freshwater flows in autumn and winter and low flow in summer. Tide height also influences water level and flooding. There can be dramatic differences in the availability of and access to salmonid estuarine habitats during freshets and during the tidal cycle. Cederholm et al. (2000) concluded that the "most fundamental concept in understanding the estuarine ecology of juvenile salmon is that the salmon do not respond to a singular habitats *per se*, but rather interact with a landscape mosaic of habitats in response to changing migratory mandates, tidal cycles and freshwater runoff events."

In summer in the small coastal estuary of Carnation Creek, juvenile coho have been observed holding in the freshwater lens and feeding in the denser seawater below (Tschaplinski 1982,1987). Similar feeding behaviours for chinook and coho juveniles were noted in the Campbell River estuary (MacDonald et al. 1987), for chinook and chum salmon in the Nanaimo River (Healey 1979a,b). Juvenile coho were present in the upper intertidal portion of the Salmon River estuary (Northern Vancouver Island) from May through November with peak abundance occurring in August (Atagi 1994). Atagi (1994) noted that estuarine coho aggregated into small groups and were infrequently aggressive when compared to stream resident fish. Tschaplinski (1982) estimated that 10% of the Carnation Creek's juvenile coho population (20% of coho biomass) resided in the upper estuary prior to autumn freshets. This form of life history does have risks associated with it as a major estuarine coho fry kill was noted during a hot-dry spell (August 28/1982; > 300 dead fry observed at low tide at Carnation Creek). In autumn following the first freshets, the estuarine reared coho had disappeared from the estuary and it was presumed they had entered the ocean. Some of these juveniles were marked and some did contribute to the adult return in later years (Tschaplinski 1987,1988).

The fate of juvenile coho reared in the estuaries of coastal rain-dominated watersheds in summer is still questionable. A portion may enter the ocean directly (physiologically capable, salt-water challenge) and contribute to later adult returns (Tshaplinski 1987,1988). However, an unknown portion of these juveniles may re-enter freshwater drainages when access becomes available during the autumn freshets. A small seasonal tributary (Dick's Creek) flows into the upper estuary of Carnation Creek. This tributary is typically dry for its lower 300m during late summer. During 1987 a small fence was placed on the tributary just above its confluence with Carnation Creek's upper estuary. Immediately following the first autumn freshets, large (estuarine reared and marked) coho were observed entering and moving up this small drainage as access became available (Brown, unpublished Carnation Creek data). Thus, not all the summer estuarine reared coho had dispersed into the ocean in autumn (presumed by Tshaplinski 1987). A similar estuarine rearing pattern was noted in Alaska (Thedinga and Koski 1984) and it was speculated that some of the summer rearing juveniles moved back up the creek into freshwater in autumn. Estuarine rearing of coho has been reported for two other Alaskan creeks (Halupka et al. 2000) where "large juveniles were caught moving upstream into fresh water in the fall, and these juveniles showed signs that they had been in salt water."

At Poett's Nook Creek (near Carnation Creek) a similar autumn disappearance of estuary reared coho has been noted (Brown, unpublished Carnation Creek data). During the summer four small drainages within 800 m of Poets Nook Creek were surveyed and found to be totally dry. The following winter, juvenile coho were recovered from two of these drainages. Their presence could only be explained by a migration from Poett's Nook Creek, across the small salt-water bay (possibly on the fresh-water lens in autumn), and up into the seasonal drainages. It might be noted, that many of our coastal inlets have an extensive fresh-water lens in autumn and winter, possibly facilitating this type of behaviour.

Lacustrine and Pond Habitat (Coastal)

Beaver Ponds

The activities of beaver influence watersheds in both coastal and interior regions of B.C. Beavers build dams in areas with wide valley-floors (floodplains), narrow streams, low gradient streams, high grass/sedge cover, and low red alder (Alnus rubra) and shrub cover (Suzuki and McComb 1998). Beaver dams are generally built on low gradient reaches and can create sizeable wetlands on floodplains (Collen and Gibson 2000). Collen and Gibson (2000) considered beavers to be a "keystone riparian species" that can change the landscape and create new ecosystems. However, in a few cases dams may become obstructions to migration and sediments may be deposited on top of former spawning areas. Beavers can also have a significant influence on the riparian zone by altering its composition, form, quality and kinds of allochthonous inputs (Naiman et al. 1984).

The stream above a beaver dam changes from lotic to lentic conditions and may provide rearing fish with refugia from high and low flows. Beaver ponds are utilized by juvenile coho salmon as both summer and winter rearing habitats (Elliott 1992; Leidholt-Bruner et al. 1992; Nickelson et al. 1992; Wilson et al. 1979). Beaver dams store water and slowly release it during drier seasons thus augmenting fish habitat in downstream reaches. Beaver ponds in the Taku River, may produce over 25% of the watersheds coho smolts (Murphy et al. 1989). On the Carnation Creek floodplain one of the off-channel winter rearing sites studied by Bustard and Narver (1975a) was associated with a series of remnant beaver ponds (dry in summer).

Lakes

Lake and pond rearing by juvenile salmonids has been clearly demonstrated throughout the Pacific Northwest (Fielden and Holtby 1987; Foerster and Ricker 1953; Swales et al. 1988; Bams 1990; Wilson et al. 1979; Mason 1974). In Alaska, coho smolts from lakes were larger than those produced from streams (Halupka et al. 2000). The largest smolts were obtained from a salt-water lake. Watersheds with lake reared smolts had higher mean freshwater ages, a wider range of age classes, and higher survival rates. Smolt production from the two lakes on the Skagit River was estimated at 20 coho smolts/ha (Beechie et al. 1994). In the Keogh River watershed, juvenile coho, may move into lakes soon after emergence and use near-shore lake habitat from June onward (Irvine and Johnston 1992; Swales et al. 1988; Johnston et al. 1987). Juvenile coho have been captured from Skidegate and Yakoun lakes on the Queen Charlotte Islands (K. Simpson, personal communication). Juvenile coho have also been studied in lakes within the Cowichan River watershed (Fielden and Holtby 1987) and Great Central Lake, B.C. (Mason 1974).

Most coho fry that rear in lakes occupy the near-shore littoral zone (Mason 1974; Bryant et al. 1996; K. Simpson, personal communication). Cutthroat trout also appear to use the littoral zone (Bryant et al. 1996). Based on visual observations, Mason (1974) suggested the vast majority of juveniles reared within 1-10 m of the water's edge and were distributed contagiously with low site specificity. He estimated coho densities in Great Central Lake of 0.55 coho/meter of shoreline in mid-summer. In the Chignik Lakes, Alaska, the highest catch rates of coho juveniles in gill-nets were within 20 meters of shore (Ruggerone and Rogers 1992). Their evidence suggests that approximately 50% of the coho salmon captured during a vertical distribution test were within 2 m of the surface.

In Harrison Lake, a study comparing littoral and limnetic areas is attempting to determine fish diversity, abundance, and biomass in different habitat types (Hume et al. 2000). Chinook, coho, and mountain whitefish (*Prosopium williamsoni*) juveniles were captured in large numbers by beach seine (nearshore), while mid-water trawl catches were dominated by sockeye salmon, longfin smelt (*Spirinchus thaleichthys*) and three spine stickleback (*Gasterosteus aculeatus*). Chinook and coho juveniles were more abundant over nearshore bedrock and rubble substrates than over gravel and mudflats. They were also more abundant in early June (Hume et al. 2000).

In Chilliwack Lake juvenile coho were captured in minnow traps during autumn (Fedorenko and Cook, 1982). Fedorenko and Cook (1982) reported that the best trapping sites were on moderately steep shorelines (30-45^0) over rubble substrates with log and stump debris, while creek outlets were less productive. This finding is contrary to observations by Graham and Russell (1979) on a snow dominated interior lake (Shuswap Lake). They found juvenile chinook and coho salmon rearing in shallow delta-lakefront sites during the period of time (May-July) when flood-waters inundated these areas.

Swain and Holtby (1989) compared lake and river reared coho juveniles in Mesachie Lake, B.C. They noted considerable differences in behaviour and morphology and speculated that these differences were an adaptation to a lifestyle of schooling in the lake. Half the coho produced from the Cowichan River system may rear in lakes (e.g. Mesachie Lake, K. Simpson, personal communication). Coho were observed moving in schools along the break line of the littoral zone, were often associated with aquatic weeds, and higher densities were noted near tributaries (may be temperature related). They were not captured in the pelagic zone of the lake.

Periodic flooding can be extensive on small coastal lakes in winter (Figure 10). The winter and spring diets of coho residing in small coastal lakes and the relationship between flooding, fish movement and feeding is unknown. This information is required to assess the importance of coastal lake foreshores and seasonally flooded lake margins in coho production and survival.

Figure 10. The extent of flooding onto surrounding fields following a winter rainstorm. Photo taken from the edge of Northy Lake in the Black Creek watershed.

Mason (1974) examined the diets of 238 juvenile coho rearing in Great Central Lake, B.C. They consumed mainly terrestrial and winged insects. He reported that in spring winged dipterans comprised 80% of the diet, while dipteran larvae were uncommonly eaten most of the year but some were consumed in late spring. In summer and autumn coho diet was still comprised of winged Dipterans, but over half of the diet became; Hymenoptera (ants), Hemiptera (aphids), Thysanoptera (thrips) and occasional mites, beetles, collembola and spiders. Mason (1974) noted that less than 11% of coho contained lake zooplankton and when present it comprised less than 5%

of the stomach contents (by volume). This selection of terrestrial and winged insects indicates that coho juveniles feed near the shore and at the water surface during summer.

The diets of juvenile coho were examined in Mesachie Lake, B.C. (K. Simpson, personal communication). In summer coho diet consisted primarily of insect items obtained near the water surface, flying and emerging insects, aquatic insect larvae, and insect items from overhanging and emergent vegetation (terrestrial). However, in late summer (August) prior to autumn rains, an abrupt shift in diet to zooplankton (e.g. Daphnia) occurred. This shift was attributed to seasonal prey availability and/or diet preference and was not due to coho size. It was speculated that the clearing of foreshore overhanging vegetation, loss of periodically flooded lowlands, reduction in cool water flows from tributaries, and removal of rooted aquatic plants could reduce juvenile coho lake rearing habitat.

Summary of Coastal Ecology

Rivers

- The use of coastal off-channel habitats is well documented throughout the Pacific Northwest for rain dominated systems.
- The larger mid-coast rivers may be glacial melt dominated. Peak flow is late in the summer and water levels can exhibit a diurnal rhythm. Fish use of glacial rivers has not been as well documented.
- Coho salmon juveniles are the main users of ephemeral floodplain habitats. Coho have developed behaviours that permit them to access and exploit seasonally flooded habitats. Cutthroat trout use the more permanent off-channel habitats.
- Migration off-channel takes place during the first autumn storms and the magnitude of those storms influences winter distribution.
- This is not a temporary redistribution lasting only for the duration of the flood event. Once an off-channel microhabitat (e.g. under a log) has been selected by a coho juvenile it will remain within 10 m of that autumn locations until spring. Isolated floodplain habitats are occupied by salmonids from November to May.
- Floodplain habitats can produce 20- 25% of a watershed's coho smolt production. Sites totally devoid of water in summer can over-winter 15% or more of a watershed's smolts.
- Ephemeral off-channel swamps and ponds in winter contain a different community of invertebrates than is found in the main-channel.
- Site morphometry appears important in over-winter survival and spring stranding. Deeper pools may provide greater protection and higher survival rates. Spring climatic conditions (e.g. warm, dry spring) can increase the risk of stranding.
- Coho growth rates are higher in spring within off-channel sites than within the main channel. Migration off-channel may be a trade off between greater growth opportunities versus risk of stranding in the spring. It is possible that smaller individuals rather than large juveniles may rear off-channel (size adverse risk of stranding).

Estuaries

- Coastal estuaries of rain-dominated watersheds are used by juvenile coho throughout he summer until the autumn rains. Juvenile coho were not found in exposed portions of coastal estuaries in winter following the first autumn storms.

- Coho use non-natal estuarine drainages and an unknown portion of the estuarine rearing population may move back upstream into fresh water in the autumn. The value of small non-natal estuarine drainages is unknown.

Coastal Lakes

- Juvenile coho rear in coastal lakes through the year.
- They occupy habitats near shore.
- A substantial portion of their diet is composed of terrestrial invertebrates through the summer but they may consume zooplankton in the autumn-winter period.
- Coastal lake foreshores may flood periodically from November to April. Water levels can rise and fall relatively quickly, and flooding may last for only a few days.
- Knowledge on fish use of flooded lake foreshores in winter is unavailable.

Snow-Melt Dominated Floodplains

Snow-Melt Hydrograph

Melone (1985) delineated the extent of the snowmelt dominated physiographic region. It includes watersheds in the interior, central and northern plateaux, and a few coastal streams. These watersheds are either located east of the coastal mountains or they have a high portion of their area at higher elevations. In the interior of B.C. most watersheds are dominated by snowmelt peak flow (Figure 11). Usually there is predictable single peak in discharge in June or July. Low flow is in March or April just prior to snowmelt. The gradual rise and fall of the hydrograph can extend over many months. Extreme floods in spring-summer primarily occur on the main stem of major rivers (Melone 1985). The lower Fraser River although coastal in climate, records it highest discharges during June as the majority of the watershed is located in the interior and is subject to snowmelt peak flows. Smith (1991) described historical Fraser Valley flooding and flood protection measures.

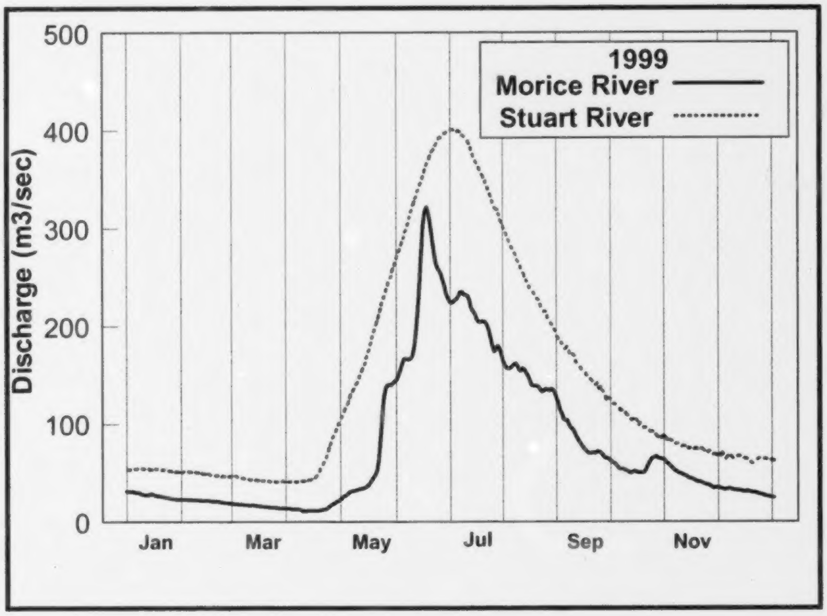


Figure 11. Hydrographs of snowmelt dominated, interior B.C. watersheds, Morice and Stuart rivers.

Interior Fish Species

The peak discharge associated with interior rivers is a highly predictable event. It occurs each year in June or July with a slight variation in magnitude based on snow accumulation and rate of melt. It is reasonable to assume that some fish species would develop behaviours that revolve around snow-melt flooding. The opportunity of fish to utilize flooded lands during the spring freshet is dependent upon their distribution, life history patterns, and behaviour in response to floods. It is possible that floodplain use may be either transient (couple of months) or continuous (persist until next spring freshet). The use of spring flooded lands by salmonids has not been as well documented as coastal off-channel use.

In the Fraser River watershed pink salmon primarily spawn in the lower and middle Fraser River, Lillooet system, and Thompson and Quesnel rivers (Birtwell et al. 1988). Pink salmon are absent from the upper Fraser and Nechako drainages. In both coastal and interior rivers, pink fry emigrate from rivers and streams from mid-April to mid May (Heard 1991), prior to spring peak flow or autumn freshets. They migrate at night, often travelling downstream faster than the current (Heard 1991). Pink fry spend less time in fresh water after leaving the gravel than other *Oncorhynchus* species. Neave (1955) felt that a broad area of bright illumination at night could be an obstacle to downstream fry migration. Pink salmon fry exhibit a strong schooling behaviour (Hoar 1958). It is unlikely pink fry use riverine and lacustrine floodplain habitats. In the lower Fraser, pink fry peak abundance is in April (Birtwell et al. 1988; Northcotte 1974), well before peak discharge associated with snowmelt. Pink fry have been found rearing in estuarine marshes and tidal channels of the lower Fraser River during high water in May-July (Birtwell et al. 1987b; Levings and Nishimura 1996: Levy and Northcote 1982).

In the Fraser River watershed chum salmon primarily spawn in the lower and middle Fraser River and the Lillooet system (Birtwell et al. 1988). The majority of downstream migration in the Fraser River is from mid-March to the end of April (Beacham and Starr 1982). Downstream migration in the Skeena extends from mid-March to mid-April (McDonald 1960). Chum fry undertake nocturnal migrations similar to pink fry, but numerous authors (cited by Salo 1991) have reported some variations from this night-time pattern. Chum fry do not school as strongly as pink and sockeye fry but do respond consistently and positively to currents by orienting downstream (Salo 1991). In the Fraser River, throughout their migration chum fry are distributed evenly across the river and are found in the top metre of water. Peak fry abundance in the lower Fraser River is in April (Birtwell et al. 1988; Northcotte 1974; Goodman 1975). It is unlikely they use riverine and lacustrine floodplain habitats as they would have migrated downstream well before peak snowmelt discharge. Chum fry rear in estuarine marshes and tidal channels of the lower Fraser River from May to July (Levings et al. 1995; Levings and Nishimura 1996; Levy and Northcote 1982).

Major sockeye salmon runs exist in the interior of B.C. and they are usually associated with lake-systems (Sandercock 1991). They spawn in 124 Fraser River drainages (coastal and interior) including the upper Fraser and Stuart Rivers (Birtwell et al. 1988). The possibility of sockeye fry and juveniles occupying floodplain habitats or being affected by flood conditions is limited by their life history patterns. Sockeye juveniles generally rear in lakes for at least one year and migrate to the sea in spring (Sandercock 1991). Lacustrine reared sockeye, migrate into lakes in spring as fry and downstream in spring as smolts. In snowmelt dominated rivers they would encounter rising hydrographs and might temporarily exploit flooded lake and river margins. The majority of sockeye fry and smolts migrate seaward in the faster flowing, mid-channel regions (McDonald 1960; Goodman 1975). In the Horsefly River, 98% of the migration is at night (Mueller and Kent 1988).

Alternative life history patterns have been documented for sockeye salmon. Sockeye fry may migrate directly to the sea (Wood et al 1989). Some of the sockeye fry emerging from below Harrison Lake migrate to, and rear in, tidal freshwater habitats associated with the lower Fraser River floodplain (Birtwell et al. 1987a). Other stocks in larger systems like the Stikine and Iskut Rivers may rear within riverine habitats (Wood et al. 1989). Wood et al. (1989) noted that larger individuals inhabited channel margins (reduced water velocity) and small sockeye occupied slack-water areas. In the Taku River, riverine sockeye represented over half of the returning sockeye salmon (Eiler et al. 1992). They reared within main-river channels, side channels, tributary streams, and upland sloughs.

Stream-type chinook migrate to sea during their second (or possibly third) spring (Healey 1983). Stream-type chinook are found throughout the upper Fraser River (Tutty and Yole 1978; Birtwell et al. 1988; Fraser et al. 1982). Tutty and Yole (1978) found that approximately 92% of the adult Nechako River chinook had overwintered in freshwater. Murray et al. (1981) reported that 93%, 100% and 90% of the adult chinook on the Bowron River, Willow River, and Slim Creek had overwintered in freshwater.

Chinook fry densities (April-July) were higher in the mainstream North Thompson River than in its tributaries (Stewart et al 1983). Juvenile chinook densities (captured in November with electroshockers) were estimated at $0.011/m^2$ for the Salmon River (Shuswap Lake) and $0.245/m^2$ for the Quesnel River (Lewis and Levings 1988). These chinook fry will likely rear through at least one snowmelt peak flow as fry and will migrate long distances downstream as water levels rise the next spring. Juvenile chinook have been captured in isolated flood channels of major rivers (Bustard 1986; Brown TJ. et al. 1989), non-natal tributaries during spring freshet (Scrivener et al. 1994), and along lake margins (Fedorenko and Pearce 1982; Graham and Russell 1979; Lewis and Levings 1988).

Ocean-type chinook tend to be found in coastal watersheds south of latitude 55N (Healey 1983) and are found in the lower tributaries of the Fraser River Basin and in the Thompson River system. They appear to be genetically distinct from stream-type chinook (Teel et al. 2000). Ocean-type chinook typically migrate to sea soon after hatching or in their first year of life after rearing for 60-150 days in freshwater (Fraser et al. 1982; Healey 1983; Taylor 1990). Typically these fish emigrate from their coastal streams prior to autumn rain induced peak flows. In the Sacramento River basin, chinook fry use the Yolo Bypass (a floodplain) as a nursery area and have higher growth rates than juveniles rearing in the river (Sommer et al. 2001a,b). The Yolo Bypass conveys up to 80% of the water flow during high water events and contains agricultural lands, seasonal wetlands and permanent wetlands. However, in the lower Fraser River Basin and Thompson River ocean-type chinook would encounter snowmelt induced flooding in May, June and July and may use seasonal flood cycles as a queue to begin downstream emigration (Healey 1991). Migratory behaviour is positively correlated with water discharge (Taylor 1990). Ocean-type, juvenile chinook rear in seasonal sloughs, marshes and tributaries of the lower Fraser River (Levy and Northcote 1982; Levings et al. 1995; Murray and Rosenau 1989).

Scott and Crossman (1973) recognized two different forms of cutthroat trout in B.C. The interior form, often called the Yellowstone cutthroat (*Oncorhynchus clarki lewis),* is limited in distribution to the upper Columbia River basin. The coastal form (*O. clarki clarki*) is found in the lower Fraser and Thompson rivers, and in most coastal systems. All Yellowstone cutthroat trout and some coastal stocks exist in snow-dominated interior watersheds. Interior trout spawn in spring and early summer usually in small gravely streams. Spawning takes place 3-5 weeks after ice break-up (Scott and Crossmann 1973) when snowmelt flows are increasing. Young cutthroat consistently preferred slow water (<0.06 m/s) and depths > 3 cm in summer (Bozek and Rahel 1991). They may move from small streams and rear in larger rivers and lakes. Interior cutthroat life history strategies require a range of freshwater habitats and may include the use of floodplain and off-channel sites. Cutthroat trout move very little in winter, "sporadically" during summer, but move more frequently and farther during spring in association with spawning (Hilderbrand and Kershner 2000). Various aspects of cutthroat trout behaviour, have been documented for interior residing fish (Brown and McKay 1995; Brown et al 1994; Jakober et al. 2000; Young 1998).

The interior snowmelt dominated rivers of B.C. support primarily summer-run steelhead trout that may spend up to five years rearing as juveniles in freshwater (Smith 2000). Winter rearing, steelhead juveniles were mostly found in the main channel of the Coldwater River (Swales and Levings 1989). They were often associated with rip-rap bank stabilization sites, a behavioural association similar to that observed for coastal steelhead and large diameter rocks (Bustard and Narver 1975a). Steelhead juveniles have been noted in side-channel ponds connected to larger rivers during spring high water, but isolated from them in autumn and winter after high water (Morice River; Bustard 1986).

Coho salmon are absent from the upper Fraser and Stuart Rivers, but occupy at least 183 Fraser River streams (Birtwell et al. 1988). The majority of these streams are located in the lower Fraser, Lillooet, and Thompson Rivers. Juvenile coho rear for one or two years within interior snow-melt rivers and lakes. Coho life history strategies regularly involve the use of minor tributaries and off-channel summer and winter habitats. Compared to other salmon, juvenile coho prefer the slowest water and often dominate riverine pools and backwaters. Stewart et al. (1983) noted that coho fry densities were higher in tributary streams compared to the North Thomson River main channel. Off-channel habitat accounted for about 20% of the total stream area in both Lemieux and Mann creeks (N. Thompson River) and approximately 20% of the juvenile coho population resided there (Bratty 1999). Juvenile coho have been documented to move into ponds isolated from the main channels of interior rivers (Swales et al. 1986; Swales and Levings 1989; Bustard 1986).

Habitat Components

Various authors have described habitats associated with interior watersheds and their floodplains (Table 2). In interior watersheds the principal environmental characteristics that influence salmon and trout habitat include "riparian vegetation, channel morphology, streamflow, deposited sediment, and winter snow and ice accumulation" (Marcus et al. 1990). Most salmon and trout species will spawn in terrace tributaries, braided side channels, and groundwater fed channels of larger systems (Bonnell 1991; Heard 1991; Sheng et al. 1990). However, the use of floodplains by juvenile salmon (primarily chinook and coho) will be the focus of this discussion. In interior streams, access to off-channel habitats such as beaver ponds, riverine ponds, and flooded meadows is more restricted than in coastal streams. Access may only be available for a few months during high water (Bustard 1986). Two distinct periods of juvenile salmonid movement have been documented. The first occurs as water levels rise in spring and summer (snowmelt) and the second takes place in autumn prior to the onset of winter. Some interior rivers may have an autumn, rainfall induced, freshet prior to the onset of winter (e.g. Coldwater River; S. Bennett personal communication).

There are two different behaviours associated with peak flooding and floodplains in interior snowmelt dominated systems. First, in interior rivers juvenile salmonids encounter flooding in spring and early summer during downstream fry and smolt migrations. Juvenile salmonids may temporarily occupy flooded riverbanks (Brown et al. 1986), lake shores (Russell et al. 1980), small non-natal tributaries (Scrivener et al.1994; Murray and Rosenau.1989), and tidal marshes (Birtwell et al. 1987b; Levings et al. 1995) during spring high water. These salmon and trout juveniles must return to the main-channel prior to the decline in seasonal peak discharge or they have the potential of being stranded in minor depressions as water levels drop. Second, juvenile salmonids may access off-channel sites (often side channels containing deep pools, ponds, permanent sloughs, and tributaries) during high peak flows in spring and they must remain in these sites until the next spring peak flow provides access back to the main-channel (Bustard 1986; Brown TJ. et al. 1989). Movement between the main-channel and isolated habitats associated with the floodplain must occur at this time, because habitats are often connected for only a few short months.

The difference between the two different uses described above may simply be related to the physical nature of the river channel, magnitude of the summer peak flood and the type off-channel habitats the fish venture into prior to disconnection from the main-channel. Fish can move laterally away from the main channel and enter flooded lands as water levels rise in spring and summer. It is possible that much of the lateral movement is either associated with opportunistic feeding on flooded lands or the seeking of refuge from higher velocity waters, but this has not been documented for the interior of B.C. Stranding may be the main reason the fish remain off-channel. Their survival is dependent upon adequate water of suitable quality through summer, winter, and the following spring. Some fish may have been fortuitously stranded in habitats where low water levels, ice conditions, predation and poor water quality do not cause mortality. Others are stranded and lost as water levels drop through the year.

In summer and autumn, salmonids may move out of the main channels and into habitats seeking either cold water sources in late summer or refuge, prior to the onset of winter. More tempered groundwater discharge may provide a thermal refuge during late summer and winter, (Cunjak and Power 1986; Hunt 1969; Smith and Griffith 1994). Juvenile salmonids (mainly coho) have been documented moving into interior off-channel ponds and alcoves to over-winter (Swales et al. 1986; Swales 1988; Swales and Levings 1989). Fish in autumn may also move into the main-channels from smaller tributaries (Chapman and Bjornn 1969), move from main channels into tributaries (Bustard 1986), move up or downstream within a watershed, or reside within protected micro-habitats (e.g. boulder substrate) within the main-channel. Fish remain within these over-wintering sites until the following spring.

Table 2. Description of salmonid habitats located within a snowmelt dominated floodplain.

Habitat Type	Water Level and Location	Substrate and Vegetation	Examples of Possible Fish Use
Permanent Water	Flowing or open standing water all year (rivers, ponds, lakes, terrace tributaries, and channelized streams.	Variable substrates and vegetation, dependent upon water velocities	Salmonids all year. Rainbow trout and chinook may use course gravel to over-winter (Swales et al. 1986; Levings and Lauzier 1991) coho may overwinter in alcoves and low velocity sites (Bratty 1999)
Ditches	Variable (dry to flowing) used for drainage and may be used for irrigation.	Mud/Clay substrate, Aquatic vegetation may re-colonize abandoned ditches.	May trap coho, chinook and sockeye fry in spring. Use and survival is dependent upon access and water quality. (Fleming et al. 1987)
River side—channels	Braids, capped side channels, percolation and overflow channels. Water velocity and level are variable. May contain isolated pools as water drops.	Sand, gravel, and cobble substrate. No vegetation instream, Riparian vegetation (e.g. willows, cottonwoods)	Coho, chinook and rainbow trout (Bustard 1986): Coho, chinook Dolly Varden charr and rainbow trout (Swales et al. 1986) Chinook dominate (Brown TJ. et al. 1989)
Runoff Tributary, Floodplain tributaries	Small, may be steep if associated with valley walls, flow into larger rivers. May be used for irrigation. Tidal access in lower Fraser.	Sand, gravel and boulder substrate. No vegetation instream, riparian vegetation is important	Used by chinook, steelhead juveniles during downstream migration (Scrivener et al. 1994). Also coho, chinook, and trout in lower Fraser tributaries, (Murray and Rosenau 1989)
Estuarine Drainages, Sloughs and Marshes	In lower Fraser may be dry part of year, flooded in summer, often tidal access	Variable substrate but usually fines. Possible vegetation; *Carex lyngbyei, Scripus* spp, *Typha* spp. Riparian shrubs	Chinook, chum, sockeye fry in spring (Birtwell et al. 1987a). Over-winter coho, trout. (Levings and Lauzier 1991; Levings et al. 1991,1995)
Ground water channels		Sands and gravel substrate. *Nasturtium officinale* (Sheng et al. 1990)	Coho juveniles dominate in winter (Sheng et al. 1990)
Riverine ponds and swamps	Permanent water. Water levels must be adequate to support fish in winter (ice). Often located in abandoned side-channels. May be associated with beavers.	Surface consists of organic muck blanket, Aquatic plants often present in ponds and swamps.	Coho dominate in winter (Swales and Levings 1989; Swales et al. 1986).
Lake margins	Flooded (April-Aug). Dry in winter.	Substrate dependent upon slope and wave action. Lake may flood into riparian vegetation and swampy alcoves	Heavily used by salmonid fry (chinook, sockeye, coho) during April – June, nocturnal use (Russell et al. 1980; Graham and Russell 1979; Brown and Winchell 2002)
River margins	Flooded (April-Aug). Dependent upon elevation and flood level. Dry in winter.	Sand and gravel substrate. River may flood into riparian vegetation.	Temporary. Fish may move laterally onto river margins during high water (Tutty and Yole 1978; Brown 1994)

The autumn habitat shifts would not necessarily be flood related, but could be queued by water temperature. These movements may be microhabitat shifts within the main-channels. Fish that were visibly rearing within the main channel during the day, seek cover within interstitial spaces in the gravel substrate and develop nocturnal behaviours in autumn and winter. Fish might also move into more protected alcoves, permanent tributaries, groundwater sources, deeper ponds, side channels, and beaver ponds to over-winter (Swales et al. 1986; Swales and Levings 1989). This may involve a more extensive migration. These sites must be connected to the main-channel in summer and autumn to facilitate movement, although as water levels drop through the autumn they may become isolated from the main-channel.

Riverine Habitats

Spring Flood

Chinook fry use the margins of the Nechako River (Brown et al. 1994) and upper Fraser River (Levings and Lauzier 1991) in April, soon after emergence. Downstream fish migrations may be queued to the interior snow-melt dominated hydrograph as a rise in water may coincide with the start of downstream migration (Levings and Lauzier 1989; Irvine 1986; Whelen et al. 1982). This is of concern as the spring peak flow may get earlier due to either logging activities (McIntosh et al. 1994) or changes in global climate (Levy 1992). However, peak downstream migration often precedes peak Fraser River discharge and it appears to be later as you move downstream. Lewis and Levings (1988) noted that peak downstream migration for Slim Creek chinook juveniles preceded any recorded increase in flow. Chinook fry and smolts from different rivers may emigrate at different times, but peak migration for upper Fraser River stocks is usually in May and typically ends by early July (Shepherd 1986; Fraser et al. 1982; Whelen et al. 1981; Tutty 1979; Russell et al 1983). Approximately 70% of Bowron River, chinook fry migrants, were captured between 23:00 and 02:30 hours during the peak migration period of May 7 to May 21 (Murray et al 1981). They captured 74% of the fry in the near shore traps, suggesting that chinook fry have a tendency to migrate along the river banks.

Harvey (1987) suggested that the effects of a spring flood on fish communities were influenced by small differences in the timing of reproduction and flooding. During June floods in Oklahoma, he noted small centrachids and cyprinids (< 10-mm) were susceptible to downstream displacement. Shirvell (1994) observed that juvenile chinook in Kloiya Creek, near Prince Rupert, moved mid-channel and downstream in response to increased spring flow. Bustard (1986) suggested that conditions in the Morice River during spring freshet may be "inhospitable" and juveniles were found in backwaters and side channels where conditions were more moderated. Sagehen Creek, California is subject to both snow and rain storm flows. Seegrist and Gard (1972) found that for Sagehen Creek, rain dominated winter floods decimated eggs of fall-spawning brook trout (*Salvelinus fontinalis*) while snow-melt spring floods destroyed rainbow trout eggs. They felt the timing of severe floods could change species composition. Elwood and Waters (1969) recorded the near elimination of two young age classes of Brook trout following a major spring freshet. They reported egg losses of 80-90%, fingerling losses of 68-83%, and reductions in numbers of older age classes.

Channel Margins and Lateral Movement

Juvenile chinook feed along the margins of the Fraser River during both summer (Levings et al. 1995) and winter (Levings and Lauzier 1991). Chinook fry preferred velocities of < 20 cm/sec along the margins of Idaho (Hillman et al. 1987) and Nechako Rivers (Nechako River Project 1987). There is a tendency for juvenile chinook to move into deeper main-channel waters as they grow (Chapman and Bjorn 1969; Everest and Chapman 1972; Hillman et al. 1987; Nechako River Project 1987; Lister and Genoe 1970). Juvenile chinook rearing in a third order tributary of Smith River, California; shifted from shallow margins to deeper, higher velocity waters as they grew (McCain 1989). Fish length is strongly correlated to water depth and surface water velocity (Everest and Chapman 1972). Everest and Chapman (1972) observed chinook fry residing in backwater and edgewater habitats in May. Fry numbers along the river edges sharply decreased as the river discharge peaked and juveniles were noted actively feeding at the thalweg, in the upper half of the water column in late summer. Catch in the Nechako River decreased from 5 chinook / m of river edge in mid-May to 0.5 chinook / m of river edge at the end of June (Brown et al. 1994). This was attributed to both a downstream and a lateral movement into deeper waters. Brown et al. (1994) recorded higher catches in flooded vegetation along the margins of the river and felt this may have provided a refuge from predation and a better source of food.

There appears to be a strong nocturnal use of flooded river margins. There is a movement of juvenile chinook from mid-river positions during the day to river margins at night. Chinook juveniles may forage along the river margins at night and move back to deeper water during the day to avoid predation. More chinook were captured along the margins of the Nechako River at night than during the day (Brown et al. 1994). Similar behaviour was noted in the Bridge River where chinook and steelhead juveniles exhibited nocturnal foraging year-round and all fish were nocturnal in winter (Bradford and Higgins, 2001).

Temporary Use and Stranding

The temporary use of flooded riverine habitats by juvenile salmonids has been poorly documented. Use of flooded lands is often recognized only when stranded individuals are observed in fields or ditches following a freshet. Documentation on feeding habits, residency timing, survival rates, types of flooded habitats used, and the impacts of human activities on fish is limited. I suspect the difficulty of sampling fish during flooding on a large river limits investigation of this subject.

There is however, considerable anecdotal information on stranding. Placer miners working the Fraser River in late summer have routinely reported stranded fish within gravel depressions (D. Desrochers personal communication). Stranded coho, chinook, and steelhead trout fry and parr were found in isolated flood channel pools of the Morice River (Bustard 1986). In early April, Bustard (1986) counted 78 dead salmonids within de-watered sites during several visits. Sockeye fry have been found trapped in isolated side channel pools of Stuart River tributaries (S. Macdonald personal communication). Coho juveniles have been seen stranded in flooded fields on Lemieux Creek (R. Lauzier, personal communication). In the upper Buckley Valley juvenile coho, chinook and trout have been observed stranded in fields, following spring freshet, (Tom Pendray personal communication). Fedorenko and Pearce (1982) felt it was evident that sloughs and flooded pastures were important rearing areas for juvenile chinook in the lower Shuswap River. Following spring flooding, sockeye fry and juveniles have been found stranded in drainage ditches and fields adjacent to the Horsefly River, (I. Williams personal communications).

Floodwaters overflowed the banks of the Horsefly River and carried emergent fry onto the surrounding fields (Mueller and Kent 1988). Many were trapped as water receded but numbers were not determined. Chinook juveniles were captured in a flooded campsite on the Thompson River at Spences Bridge (R. Lauzier personal communication).

In irrigation ditches within the Nicola and Coldwater valleys, chinook and steelhead were found after spring high water and were presumed lost during low flow in October (Fleming et al. 1987). Coho juveniles (> 100) were observed stranded in a 15 cm deep, 1 m wide, and 7 m long pool (remnant ditch) in the Coldwater River in early autumn (S. Bennett personal communication). It was doubtful they would survive through winter. A means of reducing stranding in irrigation ditches was examined by Finnigan (1978). He compared a gradual drop in water level with a rapid drop in water level. He felt juvenile chinook responded to a sudden drop in water by emigrating upstream or downstream.

Bradford (1997) examined the stranding of juvenile salmonids (coho and chinook) during rapid flow decreases. He felt the susceptibility of fish to stranding was a function of their behavioural response to changing flows which was dependent on species, body size, water temperature, time of year, time of day, and rate of flow reduction. Factors that can influence the incidence of gravel bar stranding included channel morphology, gravel bar slope, and size of substrate. The incidence of stranding was six times greater in colder water, more chinook fry than coho fry were trapped at lower ramping rates, and there may be a strong seasonal component to stranding. Bradford et al (1995) found fish were very vulnerable to stranding during daytime flow reductions. Salmon fry were more likely to be stranded in side channels than on gravel bars at similar ramping rates (Bradford 1997). Juvenile salmonids prefer deeper pools and this renders them vulnerable to becoming trapped in isolated pockets of water after a flow reduction. Bradford (1997) reported that 5-25% of juvenile fish remained trapped in side channels during the slowest ramping rates.

Differences in timing of peak flow, water temperatures, and sediment loads exist between large rivers such as the Fraser River and minor run-off tributaries that flow into them. The smaller tributaries are subject to local meteorological conditions while the larger rivers are influenced more by the regional climate. Juvenile chinook may use clear water in minor tributaries to avoid high sediment levels in the main river (Scrivener et al. 1994). In B.C., the use of small nonnatal tributaries has been noted in the Nechako (Russell et al. 1983) and Chilcotin rivers (Delaney et al 1982). High densities of juvenile chinook were recorded in Hawks Creek a small nonnatal tributary of the upper Fraser River (Scrivener et al. 1994). The average residence time was 9 days for chinook resided in the clear tributary water before they continued their downstream migration.

Flood Channel Rearing

The shift in habitat use by juvenile chinook from river margin habitats to deeper mid-river habitats does not appear to be a behaviour that would lead to stranding along river margins. The downstream movements of fry and juveniles, prior to peak discharges, is also a behaviour that should reduce stranding. However, juvenile chinook, steelhead, sockeye, and especially coho have been found in isolated flood-channel ponds associated with major B.C.

rivers. High densities of coho salmon (1.5-1.8 coho/m^2) and smaller numbers of chinook salmon and steelhead trout (0.2-0.3 fish/m^2) were recorded in side channels on the Nicola River (Swales et al. 1986).

A documented case of extended flood channel rearing in an interior B.C. river was provided by Bustard (1986). He examined fish movement through four side channels on the Morice River with small fish fences (maintained until freeze-up). Fish populations were assessed again in the spring during low water. He estimated an autumn population of 3,517 juvenile salmonids used the side-channels (52% coho, 30% steelhead fry, 9% steelhead parr, and 9% chinook fry). Overall survival was 43%. Chinook fry had the highest survival rate (64%) followed by coho (52%), steelhead fry (30%) and steelhead parr (21%). He attributed mortality to "stranding leading to suffocation and freezing of juveniles; low dissolved oxygen levels; predation." The side-channels with the lowest percentage of wetted area remaining in the spring were the sites of the lowest over-winter survival. The stranding of juveniles within shallow isolated pools was observed and 78 dead juvenile fish were found in de-watered sites in April. Bustard (1986) emphasized that the Morice and Telkwa rivers may not be typical of other interior rivers because they possess more side channel habitat than most other rivers.

The Waleach Channel (located adjacent to Herrling Island above Agassiz, B.C.) was examine through a full year to assess fish use (Brown TJ. et al. 1989). The duration of connection to the main river is dependent upon snow-melt peak discharge. The side channel was connected to the Fraser River for approximately 4 months (May-August), while isolated ponds existed for the remainder of the year. Beach seines were conducted on a biweekly basis and data was tabulated but never analysed (Brown TJ. et al. 1989). Juvenile chinook and sockeye as well as non-salmonids were captured (Figure 12). A similar study had been conducted in the same channel (different ponds) a year earlier (Rosberg and Associates 1987). In that study > 30% of the salmonids captured in March were coho. A maximum density of 0.07 chinook / m^2 was recorded in September 1987. This was lower than the 0.13 chinook / m^2 recorded in the neighbouring main river at the same time (Rosberg and Associates 1987).

The use of flood-channel habitats has been observed elsewhere in B.C. but has not been as clearly documented. Large juvenile coho were found in isolated side channel pools of the Coldwater and Nicola rivers just prior to spring freshet (R. Lauzier, personal communication). They must have over-wintered there. In the Nicola River just below Merritt hundreds of chinook and coho juveniles were observed packed into a semi-isolated flood channel in winter. The channel was 75-90 m long with ground water influenced > 5 ^{0}C water in winter. In the Chilcotin River juvenile 0+ chinook were found in smaller side channels during mid-summer and flood ox-bows adjacent to the river later in the year (D. Desrochers, personal communication). It was suggested these Chilcotin floodplain sites provide a safe and productive environment for chinook fry. In the upper Fraser River juvenile chinook utilized flood channels for rearing during peak spring flows (D. Desrochers, personal communication). Large aggregations of juvenile chinook and rainbow trout were observed during winter in isolated side-channels of the Thompson River at Spences Bridge (R. Lauzier, personal communication).

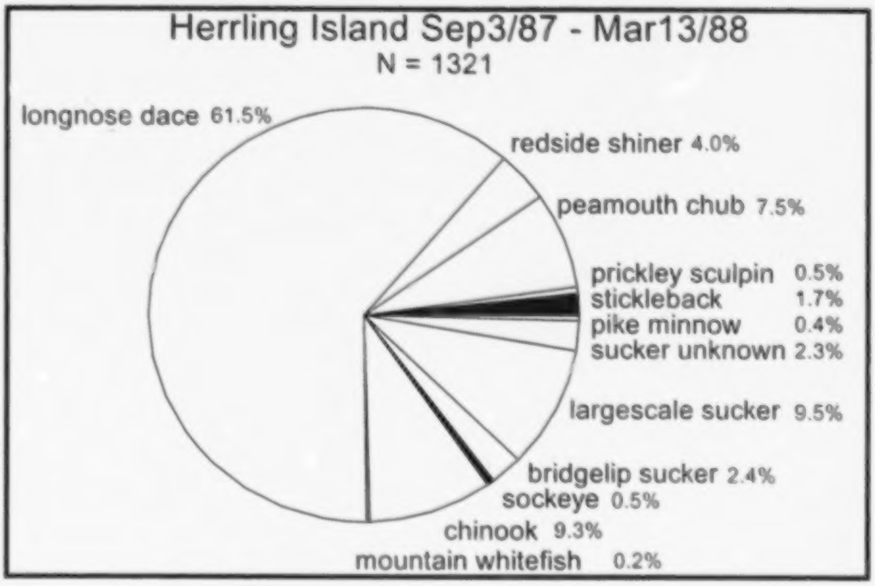


Figure 12. Numerical fish species composition from Waleach Channel (Herrling Island) after being isolated from the Fraser River (data from Brown, T.J. et al. 1989).

Off-channel ponds

The role of off-channel ponds as salmonid over-wintering habitat in the interior of B.C. has been examined in the Coldwater and Nicola Rivers (Swales et al. 1986; Swales 1988; Swales and Levings 1989). Swales et al. (1986) estimated two Coldwater River off-channel ponds to contain 0.4-1.5 fish/m^2. In winter coho dominated the off-channel pond sites, while steelhead, chinook, and Dolly Varden were scarce. In the neighbouring main river, chinook and Dolly Varden were numerous and steelhead dominated rip-rap sites, while coho were less abundant (Swales and Levings 1989). It is possible that when water temperatures drop in autumn, salmonids move from main-channel sites into low-velocity refuge habitats such as alcoves, side-channels, beaver ponds, and riverine ponds (Swales et al. 1986). However, in the Coldwater River coho juveniles have been seen isolated behind impassable beaver dams, which they could only have skirted on the spring freshet and could leave at high water a year later (R. Lauzier personal communication). In the Morice River, movement of fry into a 0.5-ha pond and juveniles out was limited to May and June during the rising peak of the spring freshet (Bustard 1986). The coho smolts leaving the pond were 20-mm larger than coho captured in side channels of the Morice River during the same period.

. Bustard (1986) suggested pond size and depth were important factors in over-wintering survival within the Morice River side channels. Small side pools can freeze solid and this has been observed in watersheds like the Morice. Swales et al. (1986) noted differences in off-channel winter survival rates in different sites along the Coldwater River and suggested that small shallow ponds may have more ice formation and possible oxygen deficiencies than larger ponds. He considered these contributing factors to over winter mortality.

Small inflows of groundwater may be important in preserving small habitats, as seen in the Nicola River (R. Lauzier, personal communication). Swales et al. (1986) noted that water temperatures in the Coldwater beaver ponds were warmer than the main-river. The importance of groundwater sources or temperatures > 3.5^{0}C through the winter has been stated by numerous researchers (Bratty 1999; Bustard 1986; Cunjak 1996; Sheng et al. 1990). However, the concept of autumn shift to off-channel habitats may not be applicable to all interior systems. A lack of suitable groundwater (thermal refuge) may limit this movement.

Juvenile salmonids may seek thermal refuge in off-channel sites during the summer. Groundwater influenced slough and side channels provide important habitats for coho rearing (Sheng 1993). Natural groundwater fed sites, isolated from the main channel of the Coldwater River, were consistently cooler than the main channel (Levings et al. 1985). One site had 8^{0}C water in late summer when stream temperatures were over 20^{0}C. These off-channel sites contained coho. Some pools as small as 2 m^2 contained coho fry of up to 80 mm in length. In the Nicola River a pool containing high densities of coho and chinook fry was 11-12^{0}C when the water temperature in the river was 20^{0}C in the early morning (Levings et al. 1985). In August, a Nicola River field survey found coho fry restricted to areas with inputs of cool ground water (Walthers and Nener 1997).

Ten small interconnected rearing ponds dug alongside the Coldwater River (compensation for highway construction) supported both summer and winter rearing juvenile coho (S. Bennett, personal communication). The ponds are groundwater fed. In summer these ponds were 14-16^{0}C when the main river was 25^{0}C. In winter pond water temperature was 4-6^{0}C when the Coldwater River was 0^{0}C. It was observed that only the top four ponds contained rearing coho in both summer and winter. It is possible that juvenile numbers were inadequate to fill all of the ponds, however it is also possible that differences in water quality (e.g. water temperature) may have influenced the distribution of rearing coho.

Autumn movement and interstitial spaces

Fish swimming ability and critical holding ability are markedly reduced at low temperatures (Griffiths and Alderdice 1972; Rimmer and Saunders 1984; Webb 1978; Cunjak 1996). A sharp decrease in performance at 8 ^{0}C explains observations of Atlantic salmon moving into the stream bed when temperature falls during autumn (Rimmer and Saunders 1984). Swimming (holding) velocity was 22-50% lower than during summer. Juvenile salmon residing in cold interior streams can avoid predation and reduce energy expenditure by selecting low velocity habitats. Behaviours used by fish might include migration to more protected sites, nocturnal feeding, or residing within the interstices of bounders, gravel, and rip-rap (Morgan 1996; Swales et al. 1986; Gregory and Griffith 1996: Contor and Griffith 1995).

In autumn, the onset of cold water may induce migrations and hiding behaviour (Chapman and Bjornn 1969). Interior cutthroat trout adults, redistribute from summer feeding areas to over-wintering areas (Brown and McKay 1995). They move in mid-September to deep pools with ice cover or sites with up-welling of warm groundwater. Movements of up to 7.6 km have been documented and they utilize the smaller diameter substrates in winter (Brown and McKay 1995). Bull trout and interior cutthroat trout make extensive (> 1-km) downstream over-wintering movements with declining temperatures in autumn (Jakober et al. 1998). Brook trout move from higher elevations to low-gradient areas where they select water velocities of < 15 cm/s but do not select for substrate types (Chisholm et al. 1987). Downstream movements of chinook in Idaho streams takes place as temperatures decline in the autumn (Hillman et al. 1987). An estimated 50% of juvenile salmon and steelhead migrated from tributaries to larger streams during the fall and winter (Chapman and Bjorn 1969). They returned to the tributaries the next spring. The autumn downstream movement of presmolt steelhead from natal streams to either the main channel or tributaries has been noted in other systems (Cederholm and Scarlett 1982; Loch et al. 1985; Leider et al. 1986).

The autumn movement of chinook fry from natal tributaries into larger rivers has been documented, but does not always occur. Migrations of chinook and coho salmon out of tributaries into the North Thompson River have been reported (Scott et al. 1982). Stewart et al. (1983) estimated chinook fry densities (April-July) were higher in the North Thompson River than in its tributaries, and suggested that most chinook fry migrate from tributary streams into the North Thompson soon after emergence. A later study found no evidence of movement from summer rearing locations in tributaries to sites considered favourable winter habitat in a larger river (Bratty 1999). Coho juveniles remained in Louis and Lemieux Creeks to over-winter and no autumn migration out of these small tributaries into the N. Thompson River was observed. No shifts in habitat use in autumn or over the winter were found in coho juveniles within tributaries of the Great Lakes (Ford and Lonzarich 2000). Despite ice and cold waters, they reported survival rates of 45% for coho juveniles over-wintering within the flowing tributaries.

Bjornn (1971) noted considerable autumn movement downstream of juvenile chinook, steelhead and rainbow, after their first summer, but less movement was observed if lots of rock (interstitial spaces) were available. Interstice size and availability are important for chinook (Steward and Bjornn 1989) and steelhead (Johnson and Kucera 1984). Bjornn (1971) and Hillman et al. (1987) noted a negative correlation between downstream autumn movement of chinook and availability of large rubble substrate. Lack of food, flow, and low temperature were not necessarily related to migration (Bjornn 1971). Thus, some of the autumn movements may be attributed to a lack of suitable substrate. In Colorado, adult cutthroat trout did not migrate in autumn (Young 1998). This lack of movement was attributed to the availability of suitable substrate.

In the Nechako River, a portion of the chinook juveniles remain through the winter (Figure 13) occupying interstitial spaces in the substrate during the day and emerging at night (C. Shirvell, personal communication; Emmett et al. 1992). Juvenile chinook are often associated with coarse highway and railway rip-rap armouring along the margins of the upper

Fraser River (Levings and Lauzier 1991), Coldwater River (Swales and Levings 1989), and Thompson and Fraser rivers (M. Crowe, personal communication). Use of interstitial substrate spaces has been recorded for Brown trout by Heggenes et al. (1993), steelhead, and Dolly Varden charr by Swales and Levings (1989). Juvenile steelhead have been found 15 cm deep in substrate during winter (Edmundson et al. 1968). Similar winter microhabitat selection has been observed in young Atlantic salmon (Rimmer et al. 1983,1984). Gregory and Griffith (1996) noted that rainbow trout juveniles in Idaho streams rarely returned to the same interstitial space on two consecutive nights. They also found significantly greater interstitial use in clear open waters compared to turbid waters or when the water surface was covered with ice.

Figure 13. The Nechako River in winter. Juvenile chinook occupy interstitial substrate spaces during the day and emerge at night.

In winter, brown trout hid during the day but at night were observed feeding while holding positions above or on the substrate (Heggenes et al. 1993). Jakober et al. (2000) observed strong nocturnal behaviour for both bull trout and cutthroat trout in Montana streams. The majority of both species emerged from concealment at night and moved into shallower water. Density of visible rainbow trout in Henrys Fork of the Snake River, Idaho, was negatively correlated with light intensity (Contor and Griffith 1995). Cunjak (1988a) consistently found juvenile Atlantic salmon hiding beneath rocks and he suggested a nocturnal activity pattern and photonegative response in winter. Water discharges in eastern Canadian streams are still high in October and December after water temperatures have declined. This combination of low temperature and high water discharge appears to impose considerable energetic demands on stream fish (Cunjak and Power 1987).

Ice Formation and Ice Dams

"Frazil ice" can be detrimental to fish and fish habitat. Frazil ice crystals form and grow in turbulent, high gradient streams when water is supercooled (Brown et al 1994). Ice crystals can abrade gills and plug gill rakers, thus suffocating fish. The frazil crystals aggregate to form "flocs" that stick to submerged objects, stream substrate, and river banks. This underwater ice is termed "anchor ice." Anchor ice plugs interstices used as winter habitat by many salmonids and accumulations of ice may form ice dams. Break-up of dams can trap, abrade and crush fish. The formation and break-up of ice dams can cause localized fluctuations in water depth, velocity and habitat availability. Maciolek and Needham (1952) found dead trout that had been stranded in a high elevation California mountain stream following the de-watering of a stream reach by an ice dam.

The avoidance of frazil and anchor ice may be important for fish survival in colder regions. Juvenile rainbow trout moved and modified their habitat use following episodes of frazil ice formation (Simpkins et al. 2000). Brown and Mackay (1995) found that many cutthroat trout in the Ram River, Alberta, made a two-stage shift in habitat associated with anchor ice formation. In Montana headwater steams bull trout (*Salvelinus confluentus*) and cutthroat trout made downstream movements during a period of anchor ice formation (Jakober et al. 1998). Cutthroat trout changed from summer territorial behaviour to gregarious groupings in autumn and winter (Brown et al 1994). They aggregated in deep pools with cover and low velocity water. Cunjak and Power (1987a) argued that water depth was not the primary factor for winter habitat selection by trout. They felt the avoidance of sites with adverse winter conditions was a major factor. Trout may select low gradient sites with low water velocity that freeze over in autumn and are insulated from supercooling (Chisholm et al. 1987).

The importance of groundwater may increase northward (Power et al. 1999). Groundwater provides overwintering habitat free of subsurface ice and fish may migrate long distances to take advantage of it. Bradford et al. (2001) suggested that groundwater flow is important in creating suitable conditions for overwintering in extremely cold regions. Cunjak and Power (1986) reported that 18 of 19 aggregations of brown and brook trout in an eastern Canadian stream were associated with 2-6^{0}C warmer groundwater. They noted that gregarious behaviour appeared to increase as water temperatures decreased. Brown et al. (1994) observed that trout occupied winter habitats devoid of woody debris and noted that this contrasted with other studies. They found winter rearing trout in the North Ram River, Alberta in areas influenced by groundwater (77%) and pools covered with surface ice (23%).

Ice formation can also reduce the amount of available habitat. In high-elevation Wyoming streams ice formation excluded from 64-84% of the cross sectional area of one site (Chisholm et al. 1987). In eastern Canada, a frazil ice dam reduced pool volume by > 80% forcing carp (*Cyprinus carpio*) and brown trout to evacuate the pool (Brown et al 2000). The distribution and survival of juvenile chinook in a small non-natal tributary of the Yukon River was strongly influenced by ice formation (Bradford et al. 2001). The severity of winter conditions on salmonids may be determined more by the amount of subsurface ice formed rather than be temperature (Chisholm et al 1987; Jakober et al. 1998). The harshest winter conditions may occur where surface ice cover is incomplete and extensive anchor and frazil ice formations occur (Maciolek and Needham (1952; Jakober et al. 1988).

River ice has been recognized as having important ecological significance to river systems (Prowse 1994). It is often associated with floods during autumn freeze-up and spring break-up. Flooding of large, northern river deltas is usually the result of ice-jams in spring (Prowse and Demuth 1996). Small ponds, lakes and depressions that are hydraulically isolated from the main river are highly dependent on flooding and flushing associated with ice-jam events.

Large ice jams have caused major flood damage on the Salmon River, Idaho (Zufelt and Bilello 1992). Merritt, B.C. suffered a damaging flood in 1991 due to an ice jam on the Coldwater River (Beltaos and Doyle 1996). Fish and egg losses were attributed to the 1987 freeze-up and the 1984 and 1991 break-up of ice dams on the Nicola River, B.C. (Doyle et al. 1994). The authors were unaware of any publications documenting the direct impacts of ice drives, freeze-ups and break-ups on a fishery resource, as direct documentation is very difficult. However, they did observe frozen redds and fish stranded on the floodplain due to diminished water levels after both break-up events.

Spring and Summer Ecology

Bratty (1999) searched and reviewed information regarding the ecology of salmonids in the interior regions of B.C. and reported it to be sparse. Literature on fish use of flooded lands and off-channel habitats in the interior of B.C. is often anecdotal. Information on specific topics such as food, feeding and growth is almost unavailable. As opposed to this, a number of studies have examined the ecology of seasonal fish habitats in the lower Fraser River and estuary (Birtwell et al. 1988; Levings et al. 1991, 1995; Levy and Northcote 1982).

It has been hypothesized that main channels of large rivers are hostile environments relative to the channel margins (Rempel 1997). High velocities and sediment transport produce a sterile environment relative to the flooded river margins. The Fraser River at Agassiz, has a mean annual discharge of 2900 m^3/sec, floods for up to 4 months, and has a mean annual flood discharge of 8700 m^3/sec (McLean 1990). Annual mean depth changes at the Agassiz gauge from 4.1m at low flow to approximately 7.9 m during a flood (McLean 1990). The Fraser River peak spring discharge is a regularly recurring event considered "hydrologically predictable" (Resh et al. 1988).

Hydrologically unpredictable floods will have a greater impact on the benthic community (Resh et al. 1988). Elwood and Waters (1969) observed a considerable reduction in invertebrates (*Gammarus)* following a severe unseasonable flood. In the Thompson River Basin, rain on snow events in 1995, resulted in substrate disturbance and turnover extending to > 1 metre below stream bottom (M. Crow, personal communication). Flashy unpredictable systems have short invertebrate generation times, organisms with high mobility, small body size, and early and rapid colonization (Poff and Ward 1989). In areas where the river has not been physiographical confined by dyking, the seasonal flood hydrograph has developed an expansive channel zone that includes near-shore margins, side-channels, and habitats isolated during periods of low flow (Rempel 1997).

Predictable seasonal flooding is compatible to the life cycles of many benthic species (Power et al. 1988; Boulton et al. 1992). Flooding serves as a queue to life history events (Robinson et al. 1992) and is important in maintaining invertebrates that represent an important food resource for salmonids (Rader 1997). As rivers flood, the increasing water depth and hydraulic stress cause changes in the physical habitat, which influences the benthic community (Church 1992). The shallow shore zone serves as a flow refugia for many benthic organisms (Rempel 1997). The invertebrate community appears to shift in distribution from the active channel to the lateral shore zone during months of peak discharge. Organisms shifted from depths of 1.5-3.0 m to shallow depths near the shore on the rising limb of the flood hydrograph (Rempel 1997). The lateral margin of the Fraser River (<0.5 m depth) was an important habitat for Chironomini, Tanytarsini sp., Rhithrogena, Baetis, and Hydropsyche (Rempel 1997).

If juvenile fish are to exploit these benthic invertebrates, they must move into the shallow shore zone of the flooding river to feed (Schlosser 1991; Sparks 1995). This depends somewhat on the feeding habits of the fish species. Coho juveniles in a tributary of Lake Ontario were associated with drift while diets of steelhead were associated with bottom fauna (Johnson and Ringler 1980). Along the margins of the main-stem Fraser River near the Waleach Channel, juvenile chinook were observed jumping out of the water, presumably feeding (Rosberg and Associates 1987). This behaviour was observed in summer (after peak discharge) and was concentrated in a 3-4 m wide strip along the river margin. The highest density of chinook fry was recorded in August (0.13 fish/m^2) and densities dropped and remained low (0.01 fish/m^2) through the winter. It is possible that the low densities recorded by Rosberg and Associates (1987) may be attributed to the lack of night sampling for nocturnal fish.

Side channels and floodplains may also have a seasonal importance to benthic invertebrates and food processing. Floodplains serve as a pre-processing area for allochthonous material trapped in seasonally flooded channels. In a Michigan woodland floodplain, major macroinvertebrate groups involved in leaf litter processing were common (e.g. Oligochaeta, Diptera, Gastropoda, Diplopoda, and Isopoda; Merritt and Lawson 1978). The major season of activity was spring. In large river systems after correction for total amount of surface area, the contribution of invertebrate biomass (e.g. oligochaetes, crustaceans, aquatic insects, and anthropods) was highest from the floodplain rather than the river (Benke 2001). The bottom of the Herrling Island side-channel ponds was "crawling with bugs," after isolation from the main Fraser River (T.J. Brown, personal communication). Invertebrate fish food in the form of amphipods (*Gammarus lacustris*) appeared plentiful within the Coldwater River ponds (Swales et al. 1986).

The degree of connectivity relative to hydrological regime alters the invertebrate community (Sheldon et al. 2002). Ephemeral and temporary waters tended to have fewer taxa than semi-permanent channels and terminal pond habitats. Sheldon et al. (2002) observed that the loss of connectivity threatened the ecological integrity and aquatic macroinvertebrate biodiversity of dryland Copper Creek in Australia. They felt that the preservation of natural flow regimes and sporadic connectivity played a crucial role in the ecosystem function of rivers. The relationships between flooding, pond size, connectivity, and benthic communities have not been examined in B.C. interior rivers.

Winter Ecology

Winter is considered a period of negligible growth and limited feeding for salmonids in cold waters (Conover 1992, Metcalfe and Thorpe 1992, Smith and Griffith 1994, Cunjak 1988b). Differences in behaviour (feeding motivation) is seasonal and may be size dependent as smaller Atlantic salmon stopped feeding in autumn while larger individuals continued to feed (Metcalfe et al. 1986). Size dependent smolting was evident in Atlantic salmon. (Metcalfe and Thorpe 1992). Large B.C. coho may be adverse to predation risk as smaller fish use feeding advantage to gain size (Reinhardt and Healey 1997). In the interior of B.C., smaller coho grew more than larger coho (Bratty 1999), possibly due to size dependent predation risk. On the coast smaller coho may practice size dependent habitat selection as the smaller coho risk stranding in off-channel sites in spring to gain size in winter (Brown 1985).

Numerous studies in which little to no fish growth occurred from October to February have been cited by Beckman et al. (2000). They indicated that growth curves closely follow seasonal temperature changes and found low stomach fullness (empty stomachs) in winter. Chinook juveniles lose energy reserves during winter (Beckman et al. 2000), condition factor and lipid reserves may decline through the winter (Cunjak and Power 1986), and mortality rate may be high in winter (Meyer and Griffith 1987, Cunjak et al. 1998). Beckman et al. (2000) measured a notable improvement in body lipid, condition factor, stomach fullness, and fish size in February-March prior to water temperatures rising above 50^0C. Riehle and Griffith (1993) noted that in Silver Creek, Idaho, juvenile rainbow trout emerged from concealment at night and fed upon mayflies in $1\text{-}4^0$C water in January. Their stomachs were fullest in the early morning.

Winter feeding has been noted in B.C interior rivers. Batty (1999) recorded coho growth rates of 0.08% body weight/day despite cold mean water temperatures in the N. Thompson River. No difference in growth rates between different habitat types was noted. Considerable invertebrate consumption was noted for chinook juveniles in the Fraser River basin during November (Lewis and Levings 1988). In the Quesnel River 92% of juvenile chinook diet consisted of Diptera. At Slim Creek they had consumed 36% Ephemeroptera, 33% Plecoptera, and 27% Cladocera. In the Eagle River their diet consisted of 42% Ephemeroptera and 49% Plecoptera. In the Salmon River (Shuswap Lake) their stomachs contained 36% Ephemeroptera, 18% Plecoptera, and 40% Diptera. In December, juvenile chinook were feeding on insect larvae in the Fraser River at Prince George (Rogers et al. 1989).

Limited winter growth has been recorded in some B.C. interior rivers. Chinook smolts were significantly heavier in April than in the previous November or had greater fork lengths in all rivers except for the Quesnel River (Lewis and Levings 1988). It was concluded that significant growth had occurred during winter. In winter juvenile chinook captured from the margins of the middle and upper Fraser River were feeding on Diptera, Tricoptera, and Plecoptera, but only slight growth was observed (Levings and Lauzier 1991). No significant change in population mean size was evident from December to April for chinook juveniles captured at Prince George (Rogers et al. 1989).

The ability of juvenile salmonids to move from cold waters into thermal refuges located adjacent to interior streams may be an important survival behaviour. Swales (1988) recorded faster growth in off-channel (warmer) ponds in the Coldwater River. Coho salmon rearing in off-channel ponds were much larger than fish rearing in the main Coldwater River or its side-channels (Swales et al.1986). Coho juveniles over-wintering in the warmer, Morice River off-channel ponds, were significantly larger in spring than main-channel reared individuals (Bustard 1986).

In extremely cold streams where considerable ice is formed, benthic community structure may be very limited. Invertebrates that survive the winter are those that can avoid being frozen through movement away from the freezing front, over-wintering elsewhere, or those that can withstand freezing. Two groups of Diptera (Chironomidae and Empididae) comprised more than 90% of the invertebrates consistently found within frozen substrate (Irons et al. 1993). In warmer locations, rivers without ice formation will support different organisms. In the upper Sacramento River in winter, Saiki et al. (2001) calculated that chinook juveniles consumed midge larvae and pupae (44% damp-dry), caddisfly larvae (18.9%), Cladocera (5.8%), and mayfly nymphs (5.7%).

Discharge patterns for interior snowmelt dominated streams may result in longer detritus retention (through autumn and into spring) than in coastal streams and detritivores may have different life cycle timing and availability to fishes (Richardson 1994). In boreal forest streams invertebrate shredder abundance was maximum in November and secondary peak abundance was noted in April (Haapala et al. 2001). Alder and birch litter had relatively faster decomposition rates than willow leaves and the different tree species represented a continuum of litter availability to shredding invertebrates. In tributaries to Takla Lake, the invertebrate drift from April to June consisted primarily of dipterans (67%), ephemeropterans and plecopterans (Choromanski et al. 1994). Most of the dipterans were chironomid larvae. Their presence in the stream coincided with the peak out-migration of sockeye fry in May. The diets of the sockeye fry were composed mainly of chironomids.

Requirements for Rearing

The requirements for successful utilization of interior floodplain habitats by salmonids differ from those of coastal systems. Extreme cold and ice formations are more likely to influence winter survival than on the coast. Snowmelt rivers exhibit a single late spring peak flow and an early spring minimum flow, compared to a series of rain driven freshets in autumn/winter and a minimum flow in late summer. Interior off-channel winter and early spring habitats must always contain suitable water, while rain dominated habitats can be devoid of water in summer if flooded in winter. The following should be considered for interior floodplain habitats:

1. Connection of off-channel sites to the main-channel may be for only a couple of months in summer during snowmelt induced peak flow. Thus, fish use is either limited to the period of flooding or they must remain off-channel until the next annual flood.
2. Off-channel sites that support juvenile fish and are seasonally disconnected from the main channel must maintain adequate water levels for an entire year
3. In many interior watersheds because of the requirement for permanent water, critical off-channel habitats used through winter/spring might be few in number and may be easier to identify.
4. Refuge (woody debris, boulders, deep waters, or aquatic vegetation) should be present to reduce predation.
5. Water quality must remain high. Thermal refugia, in the form of groundwater, are often critical for summer and winter rearing (cooler in summer, warmer in winter).
6. Deep pools in floodplain channels, alcoves, connected ponds, terrace tributaries, and beaver ponds are commonly documented rearing sites. Deep pools may be critical as; ice formation, habitat depth, and fish survival, appear related.
7. Intact riparian zones are important in providing sources of large organic debris, thermal protection, UV protection, and invertebrate food.
8. The amount and type of substrate (interstitial spaces for winter rearing) may be critical for maintaining a resident population of over-wintering juvenile fish.

Estuary Habitat (lower Fraser River)

Fish Use and Timing

The coastal floodplains of large B.C. rivers can have a unique hydrological regime when the headwaters originate in the interior of the province or when a large portion of the watershed is at higher elevations. Flooding of the Fraser Valley lowlands is caused by a number of conditions. The lower Fraser River, although coastal in climate, records it highest discharges during June as the majority of the watershed is located in the interior and subject to snowmelt peak flows. In winter the streams located in the Fraser Valley can have extremely high discharges due to rain events. Localized flooding of coastal lands can occur following rain events or rapid snowmelts, especially when drainage is impeded. High tides can influence water levels in sloughs, marshes, channels, and entrances to terrace tributaries. Tidal influence usually extends up the Fraser River to Mission (75 km from mouth) but tidal influence can reach up river for 100 km (Fraser et al. 1982).

The lower reaches of some rain dominated streams (e.g. Salmon River, Langley) were historically inundated by high snowmelt peak Fraser River water, but dyking and pumps have altered natural flooding cycles. The mouths of all large tributaries flowing into the lower Fraser River have been physically altered to the detriment of fish habitat (Langer et al. 2000).

Chinook fry use non-natal streams (May and June) associated with terrace tributaries of the lower Fraser Valley floodplain (Murray and Rosenau 1989). High tides coupled with high Fraser River water can cause flows to stop or reverse in the lower tributaries that lack flood control systems. Juveniles can enter these tributaries and sloughs and rear for a short time before entering salt water.

The young of all anadromous Fraser River fish must pass through the lower Fraser River in spring before entering the ocean. Juvenile chum and ocean-type chinook make extensive use of estuaries, pink and coho juveniles use the estuary slightly less, and steelhead trout, sockeye salmon and stream-type chinook use the estuary the least (Schmitt et al. 1994, Birtwell et al. 1988). As many as 6,250 million Eulachon (*Thaleichthys pacificus*) may spawn in the lower reaches of the Fraser River from March to May (Northcote 1974).

The migrations of young salmon through the lower Fraser River are completed prior to peak Fraser River flow in late June or early July. Peak fry and smolt migrations through the Fraser River Estuary occurs from mid-March to mid-May for all salmonids (Habitat Work Group 1978). Northcote (1974) summarized the downstream migration timing of each Fraser river salmon species. Pink fry move through the estuary from late February to early June. Coho fry are common within the lower Fraser River from mid-March to mid-June. Steelhead juveniles enter the ocean from mid-March to late June. Sockeye young are abundant from March to early July. Chum fry are first seen in the lower Fraser River (Annacis Island) in February while chinook fry appear mid-March (Rosberg and Associates 1987) both species are abundant until mid-June (Northcote 1974). Chinook fry densities of $0.63/m^2$ were recorded at Annacis Island at the end of March (Rosberg and Associates 1987). Juvenile chinook reside in Pacific Northwest estuaries from 1 to 90 days (various authors cited by Miller and Simenstad 1997).

Juvenile salmonids have a strong surface water orientation while residing in estuaries, nearshore coastal and lower riverine locations (I. Birtwell, personal communication). This predisposes the fish to utilize the shallowest of waters. Juvenile salmonids will enter < 5 cm depths to feed on flooding tides and 80-90% of the juvenile salmonids occupy water depths of < 1 m. The surface water orientation behaviour of juvenile chum salmon will continue even when surface water conditions are no longer optimal (Birtwell et al. 1998).

Habitat Types of the lower Fraser River

There has been a 70-90% loss of Fraser River wetlands used by chinook, coho, and chum salmon (Levings 2000; Langer et al. 2000; Birtwell 1988; Smith 1991). Wetlands contribute organic matter to the detritus-based food chain and they provide habitat for a large variety of aquatic and terrestrial invertebrates that juvenile salmon prey upon (Kistritz et al. 1996). Ward et al. (1992) surveyed the remaining wetlands of the Fraser Lowland, identified 398 wetland units, and classified them into six classes according to the "Canadian Wetland Classification System". Gravel bars were a new class describing periodic inundation, seasonal high water tables, adaptive vegetation, subjected to peak Fraser River discharge, and were transitory in nature. Cottonwood forest growing on the Fraser River gravel bars upstream of the Sumas River were considered as part of this unit. The surface areas of each class is listed below.

1. **shallow water** (tidal flats) Sturgeon and Roberts Banks and Boundary Bay–270 km^2
2. **marsh** (shorelines of the estuary, rivers, streams, sloughs and ponds)-61.1 km^2 shorelines, 28.1 km^2 Fraser River delta, 13.3 km^2 Pitt River Valley, and Nicomen-Hatzic 5.2 km^2 Salt marsh 2.4 km^2 -- Brackish marsh (*Carex lyngbei* and *Scirpus americanus*) 25.75 km^2 -- Freshwater marsh (cattails, sedge, bullrush) 33.0 km^2 –of which 4.1 km^2 is tidal freshwater.
3. **swamp** (floodplain forests) Surrey Bend, Matsqui and Strawberry islands, tributary stream swamps 14.2 km^2.
4. **bog** (Burns bog 15.1 km^2, Pitt Polder 1.9 km^2, Burnaby and Deer lakes) 18.9 km^2
5. **fen** (hardhack dominated) Pitt River valley 16.7 km^2 of total 23.9 km^2
6. **gravel bar** 31.4 km^2

All of these wetland habitats have the capability of supporting salmonids if access is available. Ocean-type juvenile chinook rear in seasonal sloughs, marshes and tributaries of the lower Fraser River using tidal cycles to move into seasonally flooded sites (Levy and Northcote 1982, Levings et al. 1995). Most bogs and fens are not accessible to anadromous fish. The shallow water habitats (tidal flats) could be either brackish or salt water habitats and represent 64% of the total wetland habitat (Ward et al. 1992). The primary mechanism of flooding is tidal. These areas may be influenced by river flooding (e.g. sediment deposition) and by floodplain developments (e.g. dyking). Salmonid use of the tidal flats has been extensively described (Northcote 1974; Levy and Northcote 1979,1982; Levings et al. 1991; Kristritz 1996; Levings and Jamieson 2001).

Fish use of the marsh communities (sedges and rushes) in the lower Fraser River has been studied (Levy and Northcote 1982; Levings et al. 1991; Kistritz et al. 1992, 1996). These marshes can be described as salt or brackish marshes. Detritus from marsh plants supports invertebrates, which are eaten by fish, and the plants serve as a refuge for rearing fish. Juvenile chum and chinook salmon resided in this marsh habitat. Fish use of swamp wetlands associated with the Surrey Bend have also been studied (Levings et al.1995).

Diet and Invertebrates

Juvenile salmon use of a freshwater tidal creek system draining a wetland on the floodplain of the lower Fraser River (Surrey Bend) has been examined (Levings et al. 1995). These habitats could be defined as a "Fresh Marsh" (Bauer 1977) due to the irregular wetting as a result of tidal surge and high stream flow from the Fraser River, by the characteristic Carex-Scirpus-Juncus semi-emergent vegetation, reed canary grass and hardhack riparian vegetation, and by the common organic muck and peat overlaying marine sediments. Chum, coho, chinook, and sockeye fry were abundant here in spring (Levings et al. 1995). They consumed all stages of dipteran, cyclopoid and harpacticoid copepods, Collembola, Mysids and amphipods. The upper reaches were used by juvenile coho salmon as winter habitat. In winter the coho ate dipteran pupae and larvae, and a freshwater isopod (Levings et al. 1995). A portion of the spring-summer diet of juvenile salmonids consisted of amphipods and collembola that live primarily in wet meadow and riparian habitats.

Down river benthic communities are important to fish passing directly into the estuary. Almost all sockeye fry (99%) captured in the Fraser River estuary had benthic invertebrates obtained from feeding in the river (Northcote 1974). Anderson et al. (1981) recorded chironomids, cladocerans, and copepods in fish samples taken at the mouth of Fraser River. He concluded that insects are a major prey item further upstream in the estuary and river channel locations. Chinook feeding in the estuary appears to be opportunistic (Healey 1991). Diet included; aquatic insect larva and adults, Daphnia, amphidods and *Neomysis* (Kjelson et al. 1982; Healey 1991). Juvenile chinook growth in estuaries and floodplains was superior to that found in the river (Schluchter and Lichatowitch 1977; Sommers et al. 2001b; Reimers 1973).

Sockeye fry rear in Deas Slough (Birtwell et al. 1987a,b) and Tilbury Slough (Kistritz and Macdonald 1990; Macdonald et al. 1990) in spring and summer. Depending upon tidal flushing, considerable thermal stratification can take place and residual salt water lies within deep pockets in these sloughs creating hypoxic conditions (Nassichuk et al. 1984). This condition may move into the upper portions of the sloughs. Fish tended to use the upper water column. In Deas Slough, sockeye were most abundant during high water in June and July and they remained for 5 months (Birtwell et al. 1987b). They were more abundant and had a better condition factor than sockeye rearing in channels of the Fraser River and with the majority of sockeye rearing in lakes (Birtwell et al. 1988). Sockeye diet consisted of; Cladocera 10%, Bosmina 6%, Daphnia 5%, Copopoda 45%, Chironomidae 21%, Diptera pupae 3%, Diptera adults 1%, Oligochaeta 3%, Misc 6% (Birtwell et al. 1987a). In the Tilbury slough (Birtwell et al. 1987b cites unpublished data) sockeye diet consisted of chironomid pupae 65%, collembola, adult diptera, homoptera, and cladocera, copepoda. Chum fry also rear in Deas Slough and the North Arm of the Fraser River (Levings and Nishimura 1996). Chum diet consisted of harpacticoid copepods (80%). The spring diet of juvenile coho and chinook salmon residing in an estuarine slough created on the Chehalis River, Washington consisted predominantly (78%) of dipterans (Chironomidae) and homopterans, mainly aphids (Miller and Simenstad 1997).

Interior Lacustrine Habitat

Fish Use of Lake Foreshore

Interior Lakes such as Shuswap Lake, have their lowest lake levels in March (e.g. March 22, 2001 at 344.8m) and highest levels in June or July (e.g. June 14, 1972 at 349.66m) associated with snow-melt (Kramer 2002). Lake level annually rises 3 to 4 m, freshly flooding a considerable portion of the lake margins (Figure 14) and occasionally inundating surrounding riparian vegetation (e.g. 1997 and 1999; Kramer 2002). The largest single day increase in lake level was 24 cm on May 28, 1972 (Kramer 2002). From April to June, salmonids can exploit previously dry lake margins as the water levels rise. Fish can access alcoves, channels, and bordering wetlands previous isolated from the lake.

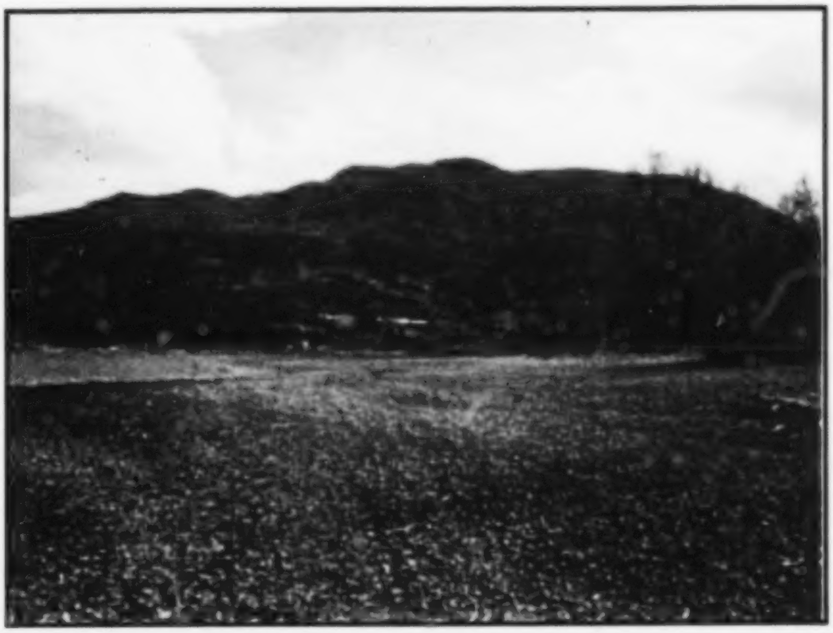


Figure 14. Extent of Shuswap Lake foreshore. Photo taken in early spring prior to rise in lake level.

In Shuswap Lake, juvenile chinook were captured from most foreshore locations surveyed, while coho were limited in distribution (Graham and Russell 1979; Russell et al. 1980). The largest catches of coho fry were in backwater areas and not on exposed beaches. Juvenile coho captured in Anderson (Seton River), Mabel (near Shuswap), N. Barrierre, Tumtum, and Momich lakes were associated with slough/alcove habitats and aquatic vegetation (K. Simpson, personal communication). The highest densities of coho in the Shuswap Lake Main Arm were associated with a backwater pond near the Adams River (Brown, unpublished Shuswap Lake data).

Chinook, coho and sockeye utilize the foreshore areas of Shuswap Lake for rearing and migration. Russell et al. (1980) noted that during dominant sockeye salmon cycle years, large concentrations of sockeye juveniles use the foreshore and in some areas may displace rearing coho and chinook. Fedorenko and Pearce (1982) captured over 200 chinook per beach seine in late June from the margins of Little Shuswap Lake. They deemed Shuswap Lake and Little Shuswap Lake littoral zones to be important chinook rearing areas. Their capture success along the lake margins declined rapidly in July. Graham and Russell (1979) documented a similar July disappearance of juvenile chinook from the margins of Shuswap Lake. They felt juvenile chinook were unavailable to beach seines when water temperatures exceed 16.1 ^{0}C. Juvenile salmon used the littoral zone between April 25 to July 6 (Russell et al. 1980). The highest densities of juvenile chinook were recorded in late April and early May from exposed sandy beaches of the lower main arm of Shuswap Lake (Brown and Winchell 2002).

Chinook, coho, and sockeye salmon fry have been captured by pole-seine along the shallow flooded margins (< 1m depth) of Shuswap Lake in spring (Brown and Winchell 2002). These lake rearing salmonids exhibited a strong nocturnal behaviour as night catches were 10 to 100 times greater than day catches (Figure 15). Juvenile salmon night catches in early June was greater than 0.5 fish/m of shore. Four possible reasons for this strong nocturnal behaviour can be hypothesized; predation avoidance, lower night water temperatures, no UV radiation at night, and increased feeding opportunities on the flooding, shallow, lake edges.

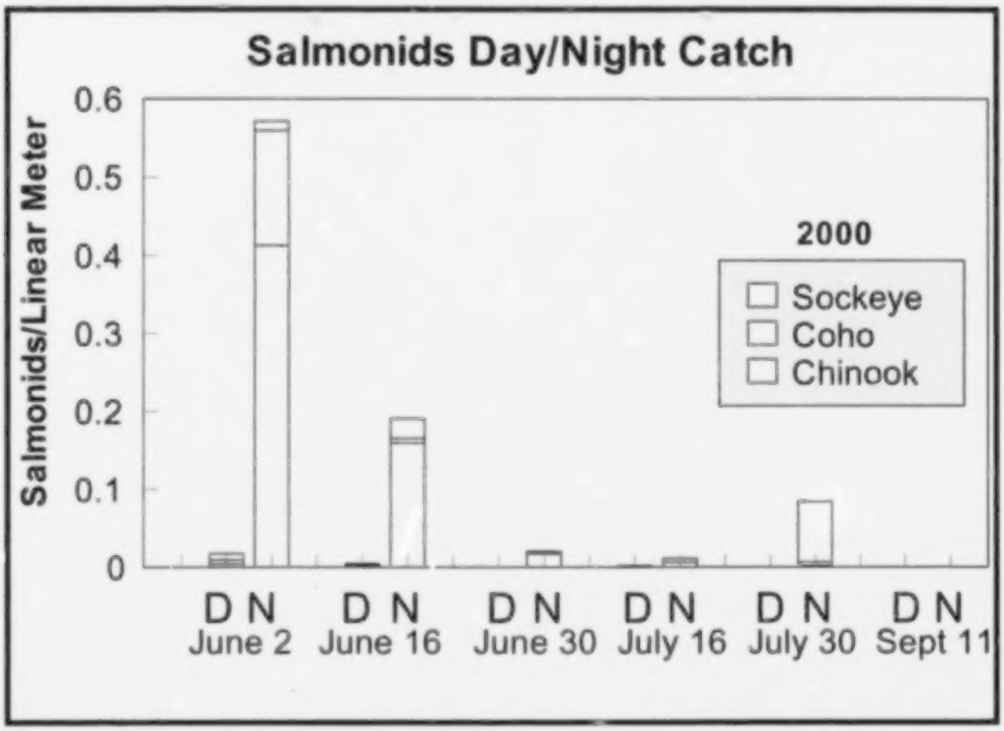


Figure 15. Shuswap Lake pole-seine catches along lake shoreline (< 1m deep), where D = day and N = night.

An investigation of fish utilization of delta-lake-front lands during high lake levels was completed for Shuswap Lake (Graham and Russell 1979). Juvenile chinook and coho used lakefront lands when floodwaters inundated the areas. The lakefront properties flood most but not all years. Graham and Russell (1979) estimated that the private properties they examined along the lakeshore would be 40% flooded for an average of 28 days each year. They suggested that chinook fry after entering the lake, remained for a short period of time in the vicinity of their natal streams. Timing of juvenile displacement from foreshore areas may be determined by lake-levels and food availability. Diminishing littoral area coincides with declining lake-levels and warm temperatures. This may stimulate young salmon to leave the foreshore and possibly the lake. Some juvenile chinook remained in the lake to over-winter (Graham and Russell 1979).

Lake Diet and Invertebrates

Graham and Russell (1979) examined the feeding habitats of juvenile salmon (10 stomachs analysed) and invertebrates availability in the littoral zone of Shuswap Lake. The dominant organisms found in the chinook stomachs were cladocerans and dipterns. Plankton samples were dominated by Copepoda (*Diaptomus ashlandi*, *Epischura nevaderises*, *Cyclops bicuspidatus*) and by Cladocera (*Bosmina* spp., *Daphnia* spp.). Crustaceans and Dipterans (chironimids) dominated benthos samples. Russell et al. (1980) examined food availability and diet of chinook juveniles in Shuswap Lake. In June stomach samples contained Dipteran pupae and adults, Daphnia spp., chironomid larvae, Homopteran adults, and Ephemeropteran nymphs. The three most numerous items in the benthic samples were Chironomida 39%, Harpacticoid 24%, and Oligochaeta 24%. It appears that for both studies, juvenile chinook were consuming a combination of benthic and planktonic invertebrates and were not feeding on a specific item.

The diet of juvenile chinook rearing within a lake and adjoining river may be very different. Chinook were captured in November from Quesnel Lake and Quesnel River and their stomach contents were analysed (Levings et al.1985). Cladocerns (86%) dominated the diet of lake rearing chinook, while river rearing diet was dominated by Dipterans (92%). Juvenile chinook rearing in the Fraser River had a high portion of their diet consisting of Dipterans, mainly chironomids, in late summer (Levings et al. 1985).

The degree of flooding may influence the type of food items available to juvenile salmonids. Chinook were captured by pole-seine within 1.0 m of depth along the shore of Shuswap Lake in June of 1999 and 2000, (Brown et al., unpublished Shuswap Lake data). Shuswap Lake water level was 0.9 m higher in 1999 than in 2000 (Kramer 2002). In 1999 the lake flooded campsites, a few beach cabins, and extensively inundated riparian vegetation. In 2000 lake-levels rose up the beaches, but did not flood the shore trees. A comparison of chinook stomach contents indicates a difference in diets for the two years (Figure 16). When the riparian vegetation was flooded; terrestrial items comprised 14.6%, small larval fish (likely Cottidae) represented 20.3%, and benthic items consisted of 42.4% of the diet. In comparison when only the unconsolidated shore was covered with water; 9.4 % was terrestrial, no small fish were consumed, and 73.1% of the diet was benthic.

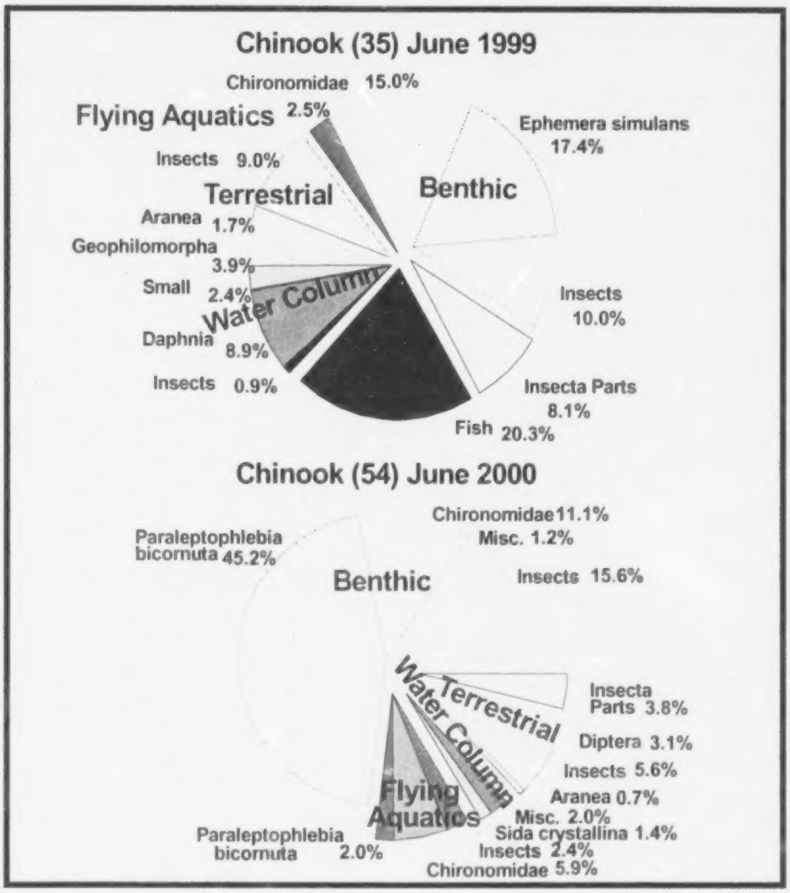
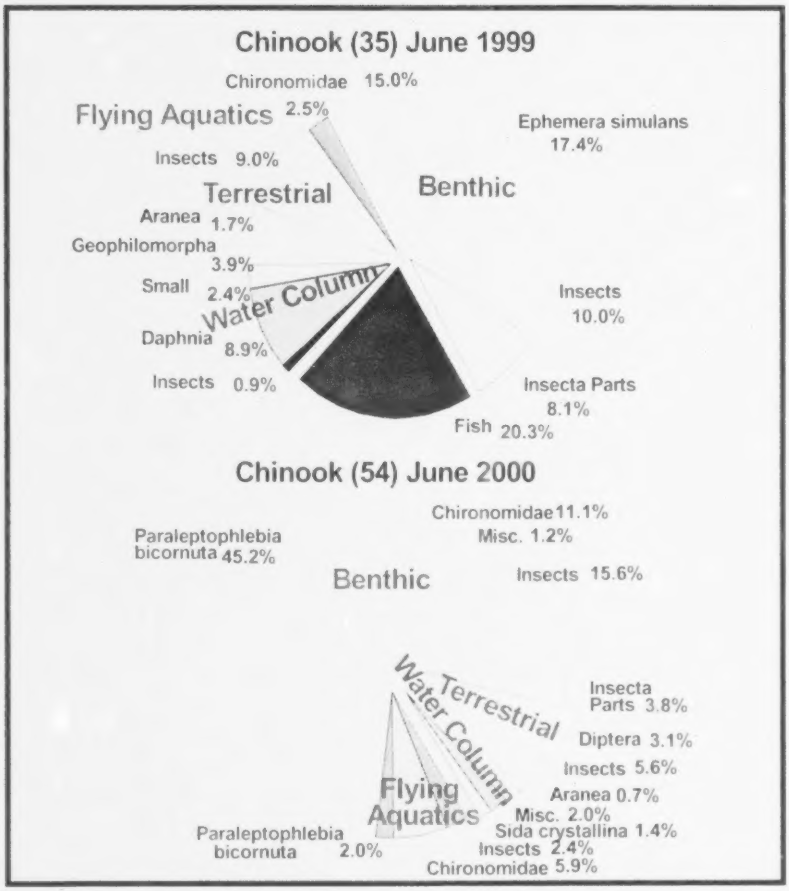


Figure 16. Shuswap Lake, chinook gut contents (by weight). In June 1999 the lake flooded into trees and bush. In June 2000 water levels were 0.9 m less and only the unconsolidated beach was flooded.

Summary of Interior Ecology

Rivers

- Snowmelt peak flow is considered hydrologically predictable; usually peak discharge is in late June. High water (flooding) occurs from May to August; low flow is in March-April.
- Many off-channel sites are only connected during high water.
- Chinook, steelhead, sockeye, and coho juveniles may occupy isolated ponds and pools within flood channels during summer and winter.
- Coho dominate off-channel ponds in the Thompson River watersheds during winter. Steelhead, cutthroat, and chinook juveniles primarily use interstitial spaces in the substrate to overwinter and they are strongly nocturnal.



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- The use of temporally flooded lands in the interior of B.C. by juvenile salmonids has been documented mainly through anecdotal observations of stranded fish following high water. Considerable research is required.
- Benthic invertebrates are more numerous along the shallow shore zone of larger flooding rivers.
- Chinook juveniles move into faster waters as they grow, use river margins at night, and may move downstream prior to peak flooding.
- Chinook and trout juveniles may move into clear non-natal tributaries, possibly as a refuge from high sediment levels during flood conditions.
- Groundwater sources modify seasonal extremes in temperature and appear to provide high quality refuge for juvenile salmonids in summer and winter.
- In the main channels of interior rivers juvenile salmon growth rates are negligible in winter but feeding does occur. When comparisons were made, off-channel juvenile growth rates were higher than the negligible main channel growth rates.
- Salmonids may move out of smaller tributaries and over-winter in larger channels. They may migrate to avoid anchor and frazil ice.
- Pond size, water depth, surface ice formation, and presence of groundwater are important factors reducing the risk of mortality through pond freezing.

Estuaries

- All salmon and trout species have the potential to use the lower Fraser River. Chinook (ocean-type) and chum fry make extensive use of the lower Fraser estuary. Pink and coho juveniles use the estuary slightly less. Steelhead, sockeye, and stream-type chinook use it the least.
- The use of wetlands, sloughs and tidal channels by salmonids has been well documented.
- Historical losses of Fraser River seasonally flooded lands and wetlands has been dramatic.
- The lower Fraser wetlands are a rich source of invertebrates.
- Flooding occurs through a combination of high spring waters from the Fraser River, flooding from lower Fraser River tributaries during winter freshets, and tidal surge.

Interior Lakes

- Interior lakes may annually rise 3 to 4 meters, peaking in June or July from a March low. This floods a considerable area of previously dry lake foreshore. Period of inundation is predictable, rise and fall of water levels is relatively gradual, and foreshore may be under water for months.
- Juvenile chinook, sockeye and coho use of the littoral zone has been well documented.
- Juvenile chinook are distributed over a wide range of nearshore habitats including exposed beaches, while coho are gregariously distributed; occupying alcoves, flooded back-channels and shallow areas often associated with emergent and aquatic vegetation.
- All juvenile salmonids appear to be strongly nocturnal moving into shallow water at night.
- The diets of river and lake rearing chinook juveniles are very different.
- The diets of chinook juveniles may change depending upon the level of flooding.

Impacts of Human Activities on Floodplain Habitats

Forestry

Stream-side Protection in B.C.

Considerable changes in B.C's forestry practices have occurred since protection for stream riparian areas on public forest lands was provided by general protection clauses (p-clauses) in the provincial forest regulations (J. Lamb, personal communications; Hartman et al. 1983). These clauses were introduced in 1956 in the Prince Rupert Forest District and were modified in 1979 to reflect a more realistic appraisal of actual operations (Brownlee and Morrison 1983). They prohibited the introduction of logging debris into streams and generally described protection measures for logging adjacent to fish streams. A joint federal/provincial/industry team developed the B.C. Coastal Fisheries/Forestry Guidelines during the 1980s and early 90's (B.C. Coastal Fisheries/Forestry Guidelines Technical Committee 1987, 1992). These voluntary guidelines provided best management practices to guide logging adjacent to fish streams and introduced a system of stream classification based on fish utilization.

In 1995 the "Forest Practices Code" (FPC) was introduced. This is a complex policy framework that includes legislation (Forest Practices Code of British Columbia Act) and both legally binding enforceable regulations and non-legally binding guidebooks that specify best management practices in riparian areas. Proposed amendments to the code (2002-future) are designed to reduce the regulatory requirements and streamline administration of the code. These and future amendments should shift the emphasis from regulatory requirements to achieving results based on standards (Results Based Code). The amended code has retained the regulated widths for reserve and management zones adjacent to streams although these may be challenged based on site-specific requirements for each stream.

Current Forest Practices Code Regulations do not require an un-logged reserve zone on coastal fish streams less than 1.5 m in width and on large rivers, with >100 m average width of active floodplain. Instead, small fish streams must have a 30-metre management zone and must be managed in accordance with the Riparian Management Area (RMA) Guidelines. Tree retention adjacent to small fish streams under the RMA Guidelines recommends retaining 50% of the trees within 10-metres of the stream bank after dominant conifer trees are removed. Trees that are rooted on the bank should not be harvested, and non-merchantable trees, deciduous trees, and understory should not be disturbed within 5-metres of the stream bank. Other general regulations prohibit damage to fish streams and de-stabilising stream channels. It should be noted that the RMA Guidelines differ between coastal and interior streams.

Streams are generally defined as watercourses having an alluvial sediment bed flowing between definable stream banks. This definition recognizes that small streams may have discontinuous stream banks and that streams and wetlands do not have to be wetted year-round. Wetlands that are accessible to fish are included in a widened management zone and have the same protection as the management zone for the relevant stream class. However, our ability to identify and evaluate seasonally flooded fish-habitat may be an issue (Hartman and Brown 1988).

Direct damage to those sites can occur when they are not identified prior to forest activities (Hartman and Brown 1988). Changes in flooding can influence the formation and succession of sites located on frequently flooded floodplains (Brown 1987). An increase in peak flows can increase the frequency of channel forming events (Hudson 2002). Also changes in the storm hydrograph due to logging and road construction could influence salmon migration timing and access to and from off-channel habitats (Brown 1985).

Potential Impacts of Coastal Forestry

Changes in Rain Dominated Hydrograph

A general equation; **$Q = Pg - (T + It + Es + Eo) + dS$**; where **Q** is the stream discharge, **Pg** is precipitation, **T** is transpiration, **It** is interception loss, **Es** is evaporation from soil, **Eo** is open water evaporation, and **dS** is change in soil moisture content; can be used to describe the basic hydrologic process acting on a small coastal rain dominated stream (Hewlett 1982; Lee 1980). This equation in illustrated in Figure 17. Forestry activities can alter each component of the cycle (Hetherington 1987). Total annual flow, seasonal flow, and peak flow can be affected and this would influence salmonid habitat and access to habitat.

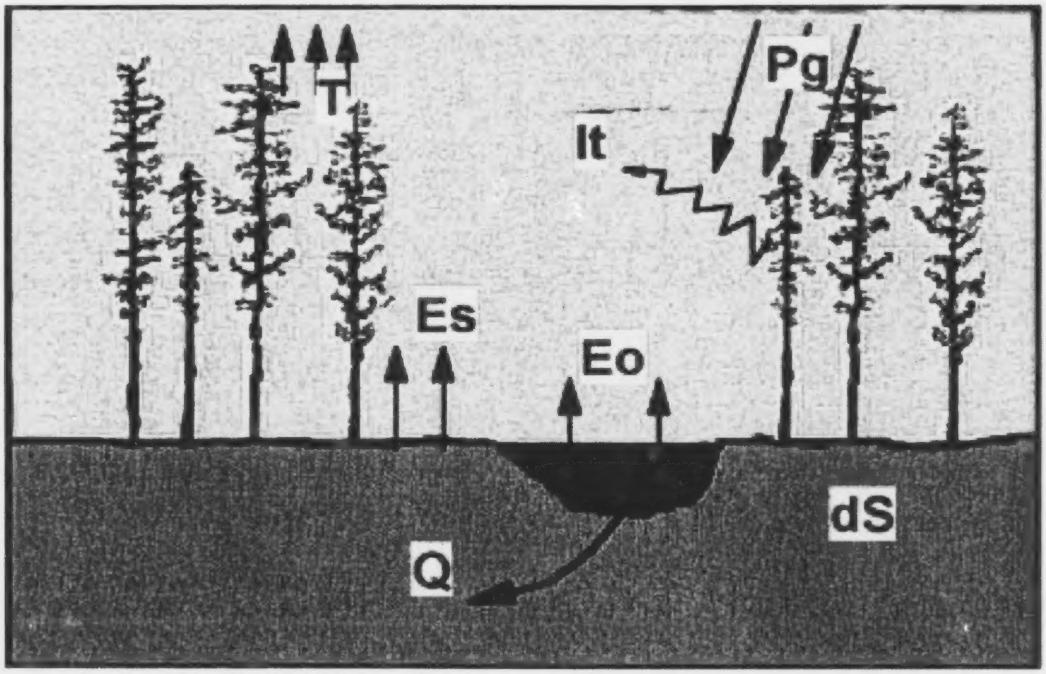

Figure 17. Hydrological processes for a rain dominated stream.

A recent review of forest practises and their effects on the hydrology of rain dominated watersheds describes in detail many of the aspects given below (Church and Eaton 2001). A major review of catchment experiments to determine the effects of vegetative removal on total water yield (Bosch and Hewlett 1982) concluded that 93 out of 94 studies showed an increase in total annual water yield following harvest. The greatest relative increase in annual flow occurred in coniferous forests and the shortest duration of measurable increased annual flow occurred in high rainfall areas. Total annual stream discharge (**Q**) increased because removal of vegetation reduced interception (**It**) and transpiration (**T**) losses (Harr 1976; Harr et al. 1982). After harvest the largest absolute increase in **Q** occurred in winter and the largest relative increase in **Q** occurred in summer (Harr and Berris 1983). An increase in total water yield of 14% followed the clearcutting of 90% of a Carnation Creek tributary stream, while a 40% clearcut in the Carnation Creek basin did not produce a significant change in total water yield (Hetherington 1982,1988).

An increase in size of peak flows and reduction in time to peak usually follows logging of coastal watersheds (Harr et al. 1982). The reasons given for these changes by Harr (1976) and Harr and Berris (1983) are:

1. soil disturbance reduces soil infiltration capacity,
2. road cuts intercept storm runoff redirecting it down slope through quicker pathways,
3. ditches increase speed of water movement.

After harvest the first storms of autumn may show the greatest increase in peak flow because soil moisture content (**dS**) remains higher on logged sites than on forested sites (Harr 1976). The method of harvest (degree of soil disturbance) influences the magnitude of peak flow increase. Peak flow increased 48% for shelterwood harvest (some standing trees retained), 35% for clear-cut, and 11% for a patchcut (Harr and Berris 1983). Harr (1976) noted that peak flows increased when soil compaction occupied at least 12% of the watershed's area. When 20-30% of a watershed was clearcut, increase in peak flow was less than 20% (Lewis 1997). Hetherington (1982) estimated the average increase in peak flows following a 40% clearcut of Carnation Creek was 20% and he attributed this increase to roads. It is possible that storm peak flows and runoff timing may be more sensitive (exhibit greater changes) in coastal B.C. than results from Washington and Oregon have demonstrated, because B.C. has a higher proportion of steep topography and shallower soils, (Church and Eaton 2001).

In recent years the effects of forest harvesting on peak flows has received renewed attention. A pivotal study by Jones and Grant (1996) used differences between the logarithms of matched peak flow pairs as a basis for analysis. They reported that forest harvesting and road building increased peak discharges in small basins by 50% and in large basins by 100%. Thomas and Megahan (1998) examined the same data with an analysis of covariance model. They reported that smaller peak flows increased by 90% for a 100% clearcut small watershed, 40% for a 31% patchcut, and peak flow increases did not occur or were not conclusive for three larger (60-600 km^2) watersheds in the western Cascades. Both studies agreed that the impact of forest harvesting diminished as the storm magnitude increased. Hudson (2002), also found that the increase in peak flow at Russell Creek, B.C., diminished relative to the storm size

Two forestry management practices are capable of altering the magnitude of the fall and winter peak flows. The first is altering the percentage of a watershed disturbed or harvested at any one time (rate-of-cut). If only small clearcuts are allowed and harvesting schedules for a given watershed are lengthened, the impact of logging activities on peak flows would not be as apparent. The second practice relates to the amount of soil disturbance (harvesting methods) and interception of storm-runoff by roads. If road construction is kept to a minimum and soil disturbance is reduced through proper placement of high-lead systems then peak flow magnitude would be affected less.

The relationship between storm-flow magnitude and salmon production is unclear. Winter populations of coho and age-0 steelhead were inversely related to maximum and mean winter discharge (Cederholm et al. 1997). In B.C. juvenile steelhead summer survival was negatively correlated with summer discharge (Smith 2000). A review of the relationship between discharge during out migration and steelhead survival indicates a positive relationship (Cada et al.1997). Discharge must be adequate to transport juveniles safely during the spring downstream migration. Knight (1980) also found a negative correlation between flow and salmon production. It may be statistically un-measurable (Hall and Knight 1981) and Smoker (1955) could not find a relationship between coho abundance and discharge. Total flow during the winter period (November to May) in relatively dryer Oregon was found to be significantly correlated to increased catch of adult salmon two years later (Scarnecchia 1981).

Smith (2000) speculated that interior B.C. steelhead survival to adulthood might be influenced by freshwater conditions more so in northern snowmelt-driven rivers than in rain-dominated rivers. He considered that more time is spent rearing in the snowmelt rivers. The lower steelhead fry mortality rates he observed during years of lower summer discharge were attributed to reduced stress in lower velocity waters during warm summers and availability of more low velocity refuge. Bradford (1997) felt that human development has obscured regional scale patterns that may have existed in earlier times. Thus, finding any correlation between salmon survival and discharge is now difficult.

Alteration of Access

The majority of juvenile coho movement off-stream into floodplain over-wintering sites occurs during the first fall storms (Brown 1985, Tschaplinski and Hartman 1982). Changes in magnitude of the first autumn peak discharge could have a profound effect on utilization of floodplain off-channel coho habitat by altering access. Higher initial peak flows could change migration patterns such that coho juveniles have greater access to more remote off-channel sites. An increase in the number and range of sites occupied and distribution of winter rearing coho could be beneficial (more habitats occupied) or could be harmful (greater potential for spring stranding from remote sites).

Harper and Quigley (2000) conducted an audit of fish habitat loss associated with 46 forest road crossings for both coastal and interior fish-bearing streams. They estimated that 3000-6000 forest stream crossing (corrugated metal pipes, log culverts, and bridges) are constructed each year in B.C. The average total loss of habitat per crossing was estimated to be; 709 m^2 for corrugated metal pipes, 575 m^2 for bridges, and 414 m^2 for log culverts. Deactivation of crossings represented a 352 m^2 loss. It was noted that 4 of the 12 corrugated metal pipe crossings were impassable to adult salmon and this represented a 6 km loss of upstream habitat. Guidelines for fish-stream crossings often fail to recognize that salmonid fry and juvenile fish may migrate upstream from spawning habitats to either summer or winter rearing habitats (B.C. Ministry of Forests 2002). When compared to adult fish, these smaller fish have reduced swimming ability and criteria for passage must be substantially lower.

Winter Water Levels and Drainage Patterns

The level of water in an off-channel floodplain site in winter is important for juvenile coho salmon. The higher the water level the more space is available to protect fish from ice formation, predation and occasional water "draw-down" during dry periods in winter. Harvesting activities can alter winter water levels by disrupting the hydrologic cycle and possibly increasing water levels (Harr 1976). Soil compaction (Rothacher 1973) and destruction of sub-surface macrochannels during harvest (Cheng et al. 1975) may reduce the rate of water loss from off-stream wetlands. An increase in volume of water entering the sites combined with a reduction in rate of outflow might raise water levels and maintain them longer, enhancing coho and trout production.

Road construction in coastal B.C. watersheds is generally conducted on the side-hills above the valley bottoms. Good road construction practices maintain existing drainage patterns. However, forest roads and associated ditches and culverts can have adverse effects on a watershed's drainage pattern (Gucinski et al. 2001). Water can be diverted away from a minor drainage and into another drainage. Diversion of water away from an ephemeral site utilized by salmonids would be detrimental. These winter rearing sites are often located at the base of the valley walls (Peterson and Reid 1984; Brown 1985). The dependence of small off-stream ephemeral swamps on minor up-slope seepage sites should be considered before roads are constructed.

Westcoast floodplains are some of B.C.'s best forestlands. Growth potential of commercial tree species is excellent on the nutrient rich, flat terrain provided adequate drainage is available. Poor drainage (high seasonal water levels) leads to chlorotic growth and high mortality of even the most water tolerant tree species such as Sitka spruce and western red cedar. Seasonally flooded lands can be rehabilitated through ditching and draining to provide high quality tree growing sites. Such silvicultural activities could completely eliminate salmonid winter habitat and prove detrimental to fish production. It is extremely important to be able to identify off-stream habitat on coastal floodplains (Hartman and Brown 1988; Belknap and Jackson 1994). All floodplain sites scheduled for site rehabilitation by forest managers (especially those located at the base of valley walls) should be examined in winter for possible fishery values.

Woody Debris

The role of woody debris in rivers and its relationship to fish habitat has been examined by numerous researchers (Sedell and Froggatt 1984; Peters et al. 2000; Beechie and Sibley 1997;

Bilby and Ward 1989; Bilby 1984; Andrus et al. 1988). Debris jams located in streams and rivers may be important in redirecting storm-flow across the floodplain. Logging practices, riparian buffer widths, age and condition of stands harvested, and forest rotation affects the location, size, and number of debris jams capable of redirecting storm flow (Brown 1985). Redirected stormflow would provide fish with access to winter off-stream habitat located in the stormflow's path and would be essential in creating new habitat sites on the floodplain. Woody debris, often deposited on river bends creates a system of secondary side channels (Maser and Sedell 1994). Logjams can rapidly raise a channel bed to elevations above adjacent floodplain surfaces, creating a complicated fluvial landscape (Abbe et al. 2000). Debris jams may trigger meander bend cut-offs thus forming abandoned channels (Sullivan 1987; Harmon et al. 1986).

Debris jams should be retained in streams and rivers and inputs of large woody debris should be managed through the retention of adequate streamside trees. Where a debris jam promotes flooding, removal of that jam could prove detrimental to salmonid production. In recent years the potential damage to floodplain habitats associated with log salvaging has become an important issue (e.g. Skeena and Kemano Rivers).

The importance of large, stable, organic debris (whole trees) as winter refuge for trout and salmon in flowing steams is well-documented (Hartman 1965; Murphy and Koski 1989; Fausch and Northcote 1992). Its value as habitat in intermittent tributaries and ephemeral swamps located on floodplains has not been examined to the same extent (Brown 1985). Brown (1985) indicated that large woody material is important for small seasonal winter habitats in the following ways:

1. Cover of woody debris could reduce predation.
2. During flooding, scouring of muck substrate under and around logs could create deep pools.
3. Logs could aid in damming water and stabilization of water levels.
4. Half rotted large logs produce a hummock (support vegetation on a raised mound). This contributes to diversity in food source and provides more cover.
5. Logs provide a substrate for invertebrates as well as a carbon source.

Pool Formation and Destruction

Pools can be created through the washing and scouring action of running water under and around obstructions such as logs. The substrate of many of the ephemeral swamps located on coastal floodplains consists of a veneer or blanket of muck (Canada Soil Survey Committee 1978; Brown 1987). If exposed these fine substrates are easily mobilized on freshets and scour pools can form even when water velocities are not extreme. The creation of pools through blasting can enhance coho and trout production on floodplains (Bustard 1983; Cederholm et al. 1988; Cederholm and Scarlett 1991). However, care must be taken that pool depth does not exceed muck substrate depth or surface water will be lost to ground water.

The loss of pool habitat and cover in small streams following logging has been demonstrated for Alaskan streams (Heifetz et al. 1986). Forestry activities may increase the rate of surface erosion and increase channel scour (bedload movement). Sediments generated on the valley walls (vertical accretions) are carried down the steep slopes and deposited on the flat valley floor. Sediments carried by the floodwaters (lateral accretions) are carried across the floodplain and as the floodwaters lose energy, they are deposited on the floodplain. Ephemeral swamps are subjected to constant settling of suspended sediments and winter rearing pools can be lost through the deposition of fines. Any forestry activities designed to reduce the production of inorganic fines would be beneficial to small ephemeral swamp habitats located on floodplains.

Semi-aquatic Vegetation

Forestry activities can have both a direct and an indirect impact on vegetation rooted in off-stream sites (e.g. rushes, sedges, and skunk cabbage). Direct impacts include mechanical destruction though yarding and felling of timber and destruction of aquatic vegetation through use of herbicides. Indirect impacts include changes in light intensity through removal of riparian vegetation, change in nutrient regime through both timber removal and prescribed burning, and changes in substrate quality through excelerated deposition of organic and inorganic fines.

Many of the off-channel sites have veneers of organic muck over coarse alluvial rock. These sites are extremely vulnerable to mechanical disturbance. A section of off-channel habitat at Carnation Creek went dry when rushes where killed due to continual disturbance and the exposed muck substrate was eroded away. Brown (1985) listed the importance of semi-aquatic vegetation rooted in the off-stream sites to be:

1. Provides stability to the muck substrate through anchoring roots.
2. Provides refuge for fish from predators
3. Provides limited thermal and U.V. cover if riparian vegetation is removed.
4. Represents a major component of the off-channel food web.
5. Dissipates the destructive energy of floodwaters.
6. Possibly provides a chemical queue to the location of off-channel habitat, thus aiding juvenile salmonid migrations.
7. Traps litter and suspended sediments and is critical to succession of habitat.

Water Quality

Water quality parameters can be altered through forestry activities (Brown 1979, 1980; Toews and Brownlee 1981; Reiser and Bjorn 1979; Everest and Harr 1982; Chamberlin 1982; Yee and Roelofs 1980; Holtby 1988). Similar patterns will exist for impacts on flowing streams and those occurring in small isolated swamps and ponds. However, the following factors must be considered in seasonal floodplain habitats:

1. Many of these habitats are dry in summer and saturated in winter:
    a) Substrate undergoes periodic oxidation followed by reduction reactions.
    b) Benthic invertebrates are restricted to those capable of surviving drought or those capable of migrating into seasonally flooded habitats.
    c) May be covered by dense growth of semi-aquatic vegetation in summer.

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2. Flow is often non-existent compared to continuous flow in a stream channel:
   a) Fines and suspended material can settle due to reduced flushing of particulate material.
   b) Increased accumulations of dissolved chemicals and organic products.
   c) Reduced water surface gas exchange due to reduced turbulence.
   d) Standing water subject to extremes in temperatures.
3. Water source may be primarily groundwater:
   a) May be low in O_2
   b) Temperatures are buffered and different from main-channel
   c) Ion concentrations may differ from main-channel.
4. Substrate consists of muck veneer or muck blanket:
   a) H_2S generated from organic material trapped in muck substrate
   b) Thin surface layer is aerobic, anaerobic below.

Forest Chemicals

At present in B.C., chemical control of vegetation (herbicides) is limited to aerial and ground applications of glyphosate (Vision) and hand applications of glyphosate (Release). These chemicals and formulations must be approved through a provincial pesticide use permit for selected applications. Considerable material has been written about the fate, persistence and toxicity of these chemicals, especially glyphosate (Reynolds 1989; Samis et al. 1992; Folmar et al. 1979; Janz et al. 1991; Wan 1989; Wan et al. 1991). Of concern is the effectiveness of glyphosate in killing emergent vegetation associated with off-channel marshes. Caffrey (1996) demonstrated the capacity of glyphosate to remove reed sp. from waterways. These chemicals should not wash into habitats occupied by fish if properly applied, with an adequate buffer (25-30m; Payne et al. 1989), under favorable conditions (no wind or rain), and prior to autumn rains when soils are not saturated. Mobile herbicide residues leach vertically downward on well drained-drained sites, but on seasonally flooded soils when saturated or during flooding the residues can move laterally (Hetherington 1989). Ephemeral stream channels may be difficult to identify and may be sprayed during aerial applications (Norris et al.1983). This may account for increases in chemicals observed in streams during the first storms after application.

Chemicals used to fertilize forests (Bengtson 1979) can enter the aquatic system. An increase in urea, ammonia and nitrate was measured in a boreal lake in Finland (Lepistoe and Saura 1998). The extra nutrients associated with the forest fertilization of a catchment area above a small lake resulted in a marked, but short-lived increase in phytoplankton. The short duration of the effect was attributed to the rapid transport of nutrients out of the lake with the spring high-flow. In Oregon, urea fertilizer was applied to Douglas fir forests with 60-90 m buffer zones maintained along 2nd and 3rd order Cascade streams (Stay et al. 1979). The community structure of benthic and drifting invertebrates did not change appreciably due to fertilization. The impact of forest fertilization was monitored at Lens Creek on southern Vancouver Island (Hetherington 1985). Urea fertilizer was applied to a second growth Douglas fir (*Pseudotsuga menziesii*) forest. Losses from the forest to the creek measured 5.9 to 14.5% of total applied nitrogen. These losses were considerably higher than previously reported estimates of < 1% (Hetherington 1985). One of the possible reasons for this higher measurement was above average early winter rainfall. In the Mohun drainage (northern Vancouver Island), urea fertilizer was applied with and without buffer zones (Perrin et al. 1984). Urea loss rates to the stream of 2.1%

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(buffer) and 5.2% (no buffer) were estimated and dissolved N levels rose 55% in Mohun Lake's largest basin and 1924% in the smallest basin. The application of forest fertilizer directly on small seasonal floodplain sites could have major implications for juvenile fish survival and growth.

Fire retardants can also enter the stream environment. The principal component of fire retardants is either ammonium phosphate or ammonium sulfate combined with dyes, thickeners, and wetting agents (Norris et al. 1983). Phos-Chek 259F is commonly used to suppress forest fires in B.C. It has a 96hr LC50 of 168 mg/L for juvenile rainbow trout (Buhl and Hamilton 2000) and a 96 hr LC50 of 218-305 mg/L for swim-up fry and juvenile chinook salmon (Buhl and Hamilton 1998). The accidental inputs of fire-fighting chemicals into aquatic environments can adversely affect fish populations (Gaikowski et al. 1996). Fish rearing in small isolated pools would be susceptible to fire retardants as only through dilution does chemical toxicity decrease.

Riparian Zone

The term riparian derives from the Latin word *Riparius* meaning "belonging to the bank of a river." The riparian zones refer to the biotic communities living along the shores of streams, rivers, lakes, and wetlands (Naiman et al. 2000). These zones possess distinct ecological characteristics and interact with the aquatic system (Swanson et al. 1982). The riparian zone is considered to be the zone of land influenced by moisture derived directly from the stream (Poole and Berman, submitted). Small watercourses and associated wetlands, such as those found on floodplains, require a delicate balance between riparian vegetation, in-channel woody debris, channel structure, semi-aquatic vegetation, soils, and water levels. The alteration of any one element will influence the others, changing the habitat and ultimately the fish utilization of such habitat. Small streams and channels have riparian areas that extend for only short distances away from the channel margins. Larger rivers have riparian zones that may extend to the edge of the active floodplain (Gregory et al. 1991).

It is beyond the scope of this paper to review all aspects of riparian zones and buffer strips. Only a cursory examination of the ways in which seasonal floodplain habitats may be impacted by riparian zone alteration can be discussed. The impacts of forestry practices on a coastal stream ecosystem have been studied in British Columbia (Hartman and Scrivener 1990; Hartman et al. 1996). Riparian Zone Management has become an integral component of watershed management strategies (Stevens et al. 1995; Naiman et al. 2000; Millar et al. 1997; Welty et al. 2002; Price and McLennan 2001; Young 2000). An excellent review of riparian management for protection of aquatic values in B.C. has recently been developed (Carver 2001). Forested buffers are considered important in maintenance of bank stability, recruitment of large woody debris, moderation of stream temperatures, reduction in sediment input, filtration of pollutants, continuation of allochthonous food-webs, and reduction in harmful ultraviolet radiation. There is rarely any debate regarding the need for buffering of aquatic resources from anthropogenic degradation (Castelle et al. 1992, 1994). In spite of this it has been estimated that 70-90% of all natural riparian areas in the United States have been extensively altered and 53% of all wetlands have been lost (Kauffman et al. 1997).

Riparian buffer size requirements are site-specific and must consider specific buffer functions. The importance of riparian vegetation increases as distance from the channel decreases. Castelle et al. (1994) reviewed buffer widths and he recommended a buffer of at least 15 m to protect wetlands and streams under most conditions. Carver (2001) reviewed B.C. buffer requirements and reported that for long term recruitment of large organic debris and to avoid detrimental increases in stream temperature, a buffer width of 15-30 m for the interior and 25-30 for the coast is required. Even wider zones 90-150 m are required to maintain riparian microclimates, support filtration of sediments and pollutants, and maintain biodiversity of plant species and terrestrial riparian habitats. Large riparian buffers should be maintained if a change in channel location might occur. Narrow buffer strips are subject to edge effects and a buffer width of 20-30m with a stream in the middle consists entirely of edge habitat (Hylander et al. 2002). Hylander et al. (2002) recommended that clear-cut logging be avoided on both sides of a watercourse and buffer width be increased to maintain biodiversity in riparian habitats.

The removal of riparian vegetation from a permanent stream can alter seasonal water temperatures (Poole and Berman, submitted; Lantz 1971) and have complex impacts on coho growth and survival (Holtby 1988). The impact of riparian removal on an intermittent coastal stream (isolated pools of water in summer) is more likely to be harmful. Canopy removal results in increased exposure to solar radiation, increasing water temperature (Brown 1969) and the magnitude of temperature increase varies directly with the degree of stream exposure (Brown 1980). Juvenile coho prefer stream temperatures between 12 and 14°C and coho thermal tolerance or LT(50) is 23-25°C (Brett 1952; Levy 1992). Maximum water temperatures can exceeding 25°C during mid-summer, diel temperature ranges are greater, and preferred temperatures will be exceeded for months at a time following riparian removal (Brown and Krygier 1970; Levno and Rothacher 1967; Brown 1980). Small drainages that would have supported summer rearing in isolated pools before canopy removal, become inhospitable following harvest.

The impact of riparian removal on ephemeral sites (dry in summer) may be more complicated. Slightly warmer temperatures in spring (Feb.-March) may benefit growth and habitat productivity. However, if riparian removal accelerates water loss or reduces water quality, than this gain could be offset by the premature death of juvenile coho and trout stranded in shallow, warm, drying pools in April and May. Brown and Hartman (1988) noted the stranding or inability of coho salmon smolts to emigrate from off-channel sites during a dry spring (water levels 37% below the 13-year mean). The exposure of the sites due to riparian removal may permit an increase in ice formation during winter cold periods. However, this is a controversial logging effect as it implies an unproven strong insulating and heat retention property for coastal over-story vegetation and may not apply to interior waters where increased snow cover (insulation) may result from reduce canopy interception (E. MacIsaac, personal communication).

The removal of trees from within the riparian zone of minor seasonal channels reduces the stability of stream banks. Stream bank integrity is lost as tree roots that hold the banks together disintegrate 5-10 years following harvest. An increase in bank erosion will increase the volume of fine materials moving through the system. Peak floods can erode portions of the channel banks even in low gradient reaches. Sediment and organic materials will be mobilized and may be deposited in the few deeper pools making them shallower. Water depth is a form of habitat refuge. The depth of water which juvenile salmonids use is dependent upon the size of the fish, type and amount of cover, and potential of predation. Deeper pools are more likely to contain water during summer dry periods and deeper pools present less risk of completely freezing up during winter. In small intermittent tributaries, fines and suspended materials can settle and there is a reduced flushing ability of settled particulate material. The removal of the riparian zone combined with an increase in sediment equates to a loss of habitat.

Following riparian harvest, erosion and bank scour will increase and more sediment will enter the stream environment. This could be detrimental to benthic invertebrate production. Benthic invertebrate production (fish food) can be reduced or eliminated by filling in of substrate with fines (Culp et al. 1986), thus reducing growth and survival of rearing fish. The greatest reduction of benthic invertebrates caused by deposition of fines has been observed on the smallest streams (Everest and Meehan 1981).

The allochthonous pathway relies upon leaf litter inputs from riparian vegetation. This leaf litter is colonized by bacteria and converted to dissolved organic carbon (DOC), required by many stream organisms or directly feeds invertebrates, which in turn become food for fish. The removal of all tree species growing in the riparian zone eliminates the source of leaf litter. Litter from each plant species decomposes at a different rate. Bacterial growth is greatest in deciduous leachates (McArthur and Richardson 2002). Thus, successional changes in composition of the riparian zone trees may influence stream microbial productivity (McArthur and Richardson 2002). Alder litter is believed to be an especially good food source for invertebrates (Mundie 1974), as it breaks down quickly and can be consumed directly without the leaves first undergoing microbial decomposition. The removal of riparian vegetation would result in a loss of benthic invertebrates that are a major source of salmon and trout food.

Following riparian removal there can be a shift from allochthonous pathways to autochthonous foodwebs (Murphy and Hall 1981). Forest harvest reduces litter inputs while increasing the level of radiate energy available to algae and plants. However, an increase in autotrophic periphyton biomass did not occur in summer at Carnation Creek following forest harvest (Stockner and Shortreed 1988) and the potential shift to autochthonous foodwebs in small seasonally flooded off-channel habitats located on coastal floodplains is speculative. The gain in energy from a direct increase in winter and spring sunlight is unlikely to equate to the loss in energy associated with reduced litter inputs from the tree canopy. Algae and plant growth is limited in winter and early spring due to reduced levels of sunlight (low solar angle and short days), reduced temperature, shortages of essential nutrient (e.g. phosphorous; Stockner and Shortreed, 1976) and the remains of last summers sedges and rushes often cover the pools. An examination of macrobenthos in small streams with "sparse riparian vegetation" in Northern Ireland (Carter and Wood 1995), reported the transition from dependence on allochthonous to autochthonous energy inputs occurred at approximately the 1-2 stream order boundary.

Many of the sites are small and narrow and the growth of shrubs and aquatic vegetation (sedges and rushes) in spring would block sunlight. Poole and Berman (submitted) described small channels as being easily shaded by topography and minor riparian vegetation. This provides "substantial resistance to the exchange of heat with the atmosphere." It is possible that an increase in the vigor of surrounding shrubs, aquatic, and semi-aquatic vegetation may yield a considerable volume of new litter material that would support allochthonous food-webs the following winter. The loss of the riparian canopy stimulated emergent macrophytes and provided autochthonous detritus for the benthic communities of small Swedish streams (Vought et al. 1998.).

Cumulative Effects of Forest Practices

Habitat modifications associated with forestry practices have both a spatial and temporal scale. A small clear-cut should have less of an impact than a large one. A small watershed would be more likely to be influenced by a single activity than a large watershed. Removal of riparian vegetation may have an immediate, but short-lived impact on stream temperatures, while the loss of large wood could influence a stream's structure for more than a century. Small habitat modifications, especially in large watersheds, are easily overlooked as they generally result in a minimal change in structure, stability, and/or productivity of an aquatic ecosystem (Panek 1979). Panek (1979) stated that "it is usually only after the fact that we perceive the cumulative impact of numerous small habitat modifications." Burns (1991) noted that "all individual effects to fish habitat result in cumulative effects to global fisheries." He recommended more experimental research at the watershed level.

Beechie et al. (1994) examined coho habitat loss at the watershed level in the Skagit River, Washington. They indicted that forestry activities had accounted for only 9% of summer habitat losses and 3% of winter habitat losses. The loss of habitats they attributed to agriculture and urban development were an order of magnitude higher. Forest harvesting has had complex and variable effects upon salmonids in the Carnation Creek, watershed (Tschaplinski 2000). A decline in chum salmon returns to 1/3 of pre-harvest returns was attributed to a decrease in quality of spawning and egg-incubation habitats. Coho adult returns declined after logging by 31%. This decline was attributed to a complex set of processes occurring both within the watershed and the marine environment.

The loss of small wetlands has a cumulative effect on a watershed (Panek 1979). The possible impacts of individual forestry practices on small tributaries and swamps located on coastal floodplains are summarized in Table 3. These impacts may be either positive or negative and there will be cumulative effects of the various practices on the quantity, quality, access to, and use of off-channel winter habitats. Impacts are also likely to be very site specific. Some practices may enhance habitat (e.g. increased water levels following harvest) while other practices have a definite detrimental impact (e.g. site drainage).

Using two off-channel sites located on the Carnation Creek floodplain, Tschaplinski and Hartman (1983) found no difference in numbers and no apparent difference in survival of winter rearing coho before and after logging. However, they did not examine the impacts during the first year of active logging. Brown (1985) observed one swamp during the time of felling and active yarding (April 1976). The waters flowing from the site were turbid and the largest single day migration of juvenile coho coincided with the day of most active yarding. A downstream movement of trichopteran larva (*Limnephilidae* sp.) on the same day was described as "completely plugging the small fence" and was the only time these larva have been noted in such numbers. Invertebrates living in isolated off-channel ponds may be very sensitive to harvesting activities.

Table 3. Summary of operational forestry activities and possible impacts on habitat located on coastal floodplains. (Adapted from Hartman and Brown 1988).

Forestry Activity	Impact on floodplain habitat
Roads	1. Altering natural drainage patterns may change existing water levels in off-channel sites. 2. Sediment eroded from up-slope positions will be deposited in off-channel sites located on the floodplain below. 3. Interception and channelization of storm-flow may alter timing and magnitude of flood events, impairing migration. 4. Culverts and bridges limit access. 5. Direct damage to sites during road construction on floodplains.
Harvesting	6. Change in tree size and woody debris volume is dependent upon forest harvest rotation length and riparian zone management. Number, size and arrangement of main channel debris jams can alter flooding patterns. 7. Rate-of-cut can change hydrologic system, peak flow magnitudes, and water levels in sites. 8. Riparian harvest or inadequate buffers may increase UV and alter water quality (temperature, nutrient loading, and sediment).
Yarding	9. Break though of impervious muck substrate and lose surface water, thus reducing available habitat. 10. Fish migratory paths (main channel and off-channel) can be destroyed. 11. Damaged substrate and exposed soils may erode into off-channel sites.
Silviculture	12. Site drainage will cause complete loss of winter habitat, as reduced water levels cannot support winter rearing fish. 13. Prescribed burning may flush nutrients and increase surface erosion. 14. Herbicide use may destroy semi-aquatic plants; altering trophic pathways and exposing muck substrates. 15. Stand Management will govern the tree species composition, changing litter input and altering trophic pathways.

Means of Reducing Impacts

The fundamental problem in reducing the impacts of forestry practices on small ephemeral floodplain habitats is our inability to identify seasonal rearing habitats (Hartman and Brown 1988; Belknap and Naiman 1994). Sites completely devoid of water in summer may be prime winter rearing habitats. Even when an off-stream site is recognized its value may be underestimated. Cutthroat trout and coho juveniles use intermittent tributaries, while coho juveniles dominate the small ephemeral swamps. It would be easier to locate and argue for protection of the more easily defined trout habitat than the more ephemeral coho habitat. Only through proper identification and evaluation can seasonal floodplain habitats be managed.

Hartman and Brown (1988) considered our inability to identify seasonal habitats as a potential problem. They listed factors that should be taken into consideration when conducting surveys to identify minor floodplain salmonid habitats. These include:

1. Conduct surveys in winter when ephemeral swamps contain water and fish.
2. Care should be taken to examine the base of the valley walls.
3. Establish the presence and degree of use by fish (minnow trapping).
4. Identify all sources of water (seepage and groundwater).
5. Identify connections and migration routes between main channel and off-channel sites (including locations where over-bank flooding occurs).
6. Note small patches of sand and gravel in minor channels where trout might spawn.

Hartman and Brown (1988) also indicated some forestry practices might retain the quality and quantity of off-channel fish habitat. These include:

1. Culverts and bridges must permit movement of juvenile fish into and out of off-channel sites.
2. Water should not be diverted away from sites during road building and ditching.
3. The active period of harvest on coastal floodplains should be in late summer when sites are dry. Current practices consider the low west-coast forests as winter logging areas.
4. Large volumes of fine organic waste (bark and branches) should be cleaned up while large woody debris should be left in place.
5. Sedimentation should be kept to a minimum. These areas should not be thought of as catch basins to protect the main-channel from up-slope disturbance.
6. All herbicides considered for forest use should not damage the various species of semi-aquatic vegetation.
7. All applications for forest site rehabilitation located on floodplains should be examined (especially those that mention wetlands or drainage).

Belknap and Naiman (1994) designed a three-step process for identifying floodplain sites potentially used by rearing juvenile salmon during the winter. First, high probability areas were delineated using geographical information systems (GIS) or digital maps with elevational data. Second, these areas were photographed using aerial mounted thermal-red-scanners. Third, possible sites identified from the remotely obtain images were incorporated into the map base.

Potential Impacts of Interior Forestry

Coastal and interior forest industries differ from each other in harvesting methods, timing of operations, and species of trees harvested (Scrivener et al. 1993). Both regions require the building of roads and the cutting of trees. However, coastal forestry practices include the yarding of timber to landings by a high-lead system. In the interior of B.C. high-lead operations are rare and "skidders" are used to drag logs to landings. Coastal harvesting is often year around (especially on low elevation floodplains), while felling and hauling of timber in the interior is often limited in season due to poor road conditions and fire risk. Interior and coastal silvicultural activities are mainly confined to site preparation, planting of commercial tree species, and limited stand tending (herbicides, thinning and pruning). The species and size of interior trees such as interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) ponderosa pine (*Pinus ponderosa*) western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*)

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Interior forestry practices can damage fish habitat in flowing streams (Chamberlin 1982; Brown 1970, Toews and Brownlee 1981; Marcus et al. 1990). The impact of forestry practices on specific habitats such as flood channels, alcoves, and isolated ponds is not as well documented. The aquatic and terrestrial environments are closely linked through various hydrologic, trophic, and nutrient cycles. Thus, forestry activities that alter the terrestrial environment may also alter the aquatic component of that watershed and ultimately influence the fisheries resource.

Many of the possible impacts to off-channel habitats described for coastal floodplain sites would be applicable to interior floodplains. There are however, major difference between coastal and interior floodplain habitats and the possible impacts of forestry practises on them. Ice formation and cold water temperatures may limit winter rearing in interior systems. In the interior there may be a greater dependence of juvenile salmonids on over-wintering substrates and groundwater. The timing of seasonal peak flows is different. In the interior the seasons of habitat use may be limited to spring flooding or may extend through summer and winter until the following spring. If extended off-channel rearing does occur then the presence of water must be continuous.

Flood Producing Processes

Two flood generating processes exist for watersheds that accumulate snow. The first process involves snowmelt during a rain-on-snow event within what has been termed the "transient snow zone". This can occur in either coastal or interior watersheds. Harr (1981) gave an explanation for this process. It tends to occur when warm, moist marine air dumps rain on high elevation snow packs. The second process is the seasonal melt of snow in a cold snow-pack region. Peak flow magnitude and time of peak discharge are governed by the amount of snow, snow distribution, and climatic conditions during snow melt. Forest harvest can influence the amount of snow accumulated, distribution of the snow, and solar energy inputs.

Process of Snow Accumulation in Openings

Figure 18 illustrates the snow accumulation process in forest openings. More snow will accumulate in forest openings, however the size of the openings is important in estimating the relative amount and distribution (Golding and Swanson 1978; Swanson and Hillman 1977). Reduced canopy interception will produce a greater accumulation of snow on the ground and change the snow distribution. The greatest accumulation of snow occurs in openings 2-4 tree heights in diameter (Golding and Swanson 1978). This is due to a combination of normal snow-fall, plus increased snow fallout (eddy effect), plus fallout from the canopy surrounding the openings. Very small openings encounter considerable canopy interception and very little snow redistribution, large openings allow higher surface wind velocities (scour) redistributing the snow from the openings into the surrounding forest. These deep accumulations of snow at the forest margins will melt slower then an even exposed snow-pack. Thus spring run-off may be later and more prolonged.

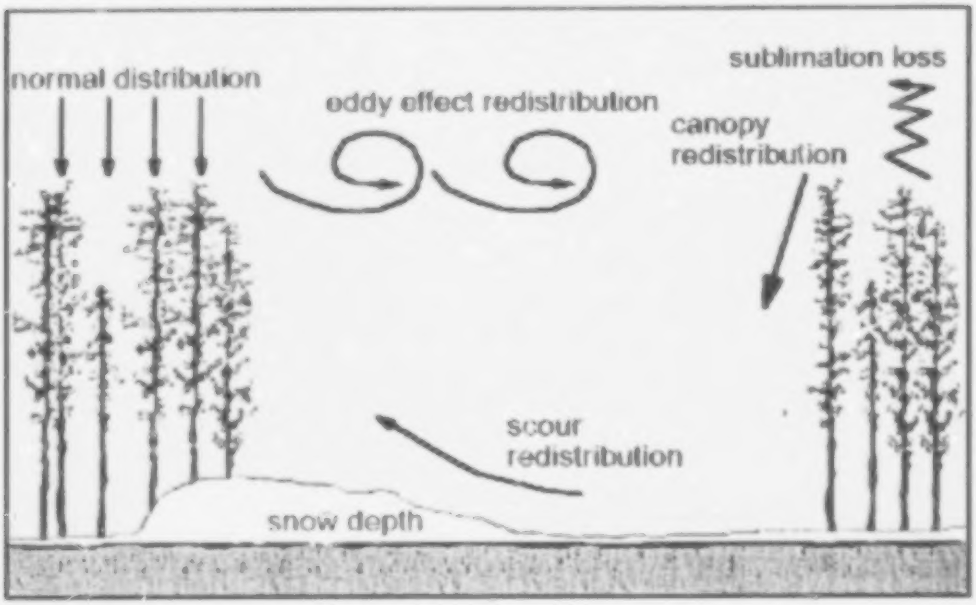


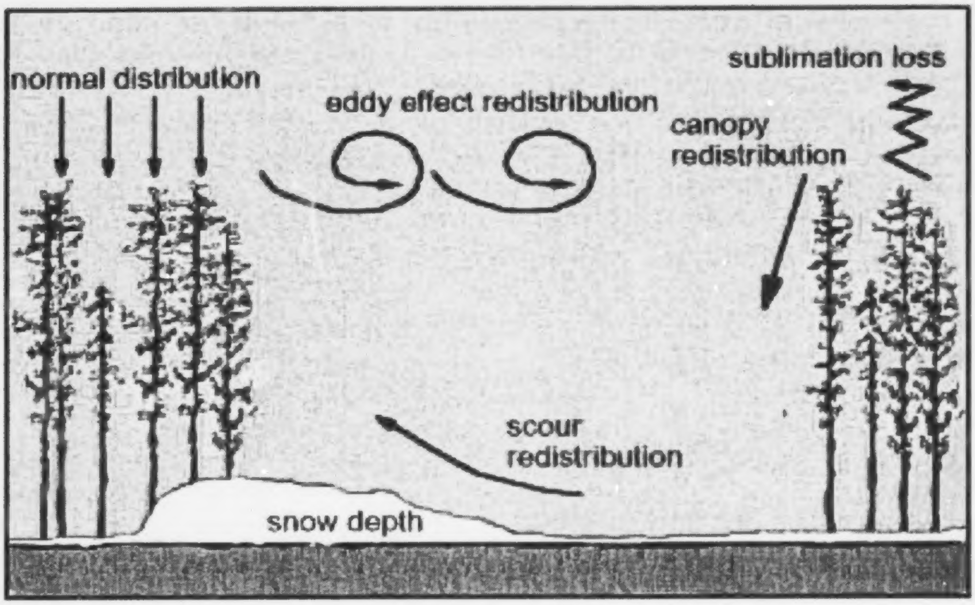
Figure 18. Snow accumulation relative to a forest opening

Process of Snow Melt

The equation: **Mt = Mrs + Mg + Mrl + Mce + Mp** describes snowmelt for both a "cold snow pack" spring melt condition and a "warm snow pack" rain-on-snow event (Harr 1981; Wilford 1982; Zuzel et al. 1983). The components include **Mt** (total snowmelt), **Mrs** (shortwave radiative melt), **Mg** (melt from ground heat), **Mrl** (longwave radiative melt), **Mce** (melt from convection and condensation), **Mp** (melt by warmer rainwater). A cold snow pack must absorb considerable energy before it "ripens" or becomes isothermal at 0°C with its capacity for free water satisfied. A warm snow pack has an interior temperature at or near 0°C, thus very little additional energy is required (Harr 1981).

In a cold snowpack region, **Mrs** is the most important single factor in the snowmelt equation (Harr 1981). However, in openings < 1 tree height in diameter, **Mls** will have a greater influence. When openings are > 3 tree heights in diameter, Mrs will reach the snow pack and maintain a high melt rate. Thus for openings between 1-3 tree heights in diameter a large accumulation of snow and lower ablation rates can be expected (Harr 1981).

The highest melt rates in the transient snow zone occur on cloudy days when **Mrs** is minimal. During a rain-on-snow event the greatest energy input to the snow pack is **Mce**. **Mg** and **Mp** are of secondary importance. The condensation of water vapour on the snowpack and transfer of turbulent energy to the snow pack through air movement dominates the equation (Beaudry and Golding 1983; Harr 1981; Christner and Harr 1982).



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Effects of Forest Harvest on Hydrology

Forest harvesting in snowmelt dominated watersheds increases total water yield (Sahin and Hall 1996; Martin et al. 2000). Clearcut logging in small interior snow melt dominated watersheds can increase annual water yield by as much as 20-30% and increased yields will be evident for as long as 30 years (Swanson and Hillman 1977). Cheng (1989) reported a significant increase in peak flow and earlier time to peak in a small interior B.C. watershed. He speculated that this could apply to larger basins if a sufficient portion of the basin was harvested. Total increase in water yield increases in proportion to the fraction of the basin area harvested (Keenan and Kimmins 1993)

The size of the forest openings is important in altering the peak flow characteristics. Reduced canopy interception after harvest will permit greater accumulations of snow on the ground (Golding and Swanson 1978). Clumps of snow in the canopy are subjected to higher rates of sublimation. Forest harvest in large clearcuts can increase total storm flow by 59% and increase peak flow magnitude by 1 ½ to 2 times (Swanson and Hillman 1977). Snowmelt floods are increased by 11% when ½ of a watershed is deforested (Anderson and Hobba 1959). Small patch cuts can reduce the magnitude of the spring peak, increase the time to peak, and increase the total water yield (Harr 1981).

The impact of forest harvest, on rain-on-snow peak flows, is slightly more complex. Numerous authors have indicated that clearcut logging will increase the magnitude of peak flows during a rain-on-snow event (Anderson and Hobba 1959; Beaudry and Golding 1983; Harr 1981; Christner and Harr 1982; Zuzel et al. 1983). The reason given for this increase in peak flow is that more turbulent heat exchange at the snow-pack surface can occur when the forest canopy is removed, thus melt rate will increase. However, snow in the forest canopy is subjected to quicker melt then snow on the ground. In situations where canopy snow accumulations are high, rate of water production will be greater from the forested area (Beaudry and Golding 1983).

In larger basins, when land cover changes represent from 5 to 25% of the area, streamflow response was not definitive in respect to total water yield, peak flow magnitude, and peak timing (Buttle and Metcalfe 2000). Buttle and Metcalfe (2000) attributed this finding to the ability of large basins to buffer hydrologic impacts of small disturbances combined with the influence of climatic variability in a large basin. Forest cover disturbance may influence the timing of peak flows as snow cover in exposed areas may ablate before appreciable melt in forest stands (Buttle and Metcalfe 2000). This would produce several small peak flows (from different tributaries), rather than a single large peak.

McIntosh et al. (1994) recognized that natural hydrological patterns in a basin influenced the availability and quality of fish habitat. Changes to the natural discharge regimes can interact with the processes that maintained and created fish habitats, thus adversely altering habitats and fish populations. McIntosh et al. (1994) felt that changes to peak flow magnitude, the timing of peak flows, and low summer flows were critical to evaluate. They used 50 years of flow and precipitation data from experimental basins in the upper Columbia River and examined long-term trends. They found a significant increase (near doubling from 1935 to 1992) of base discharge, a decrease in annual and winter precipitation, no change in magnitude of peak flows, and a shift in time of peak discharge to earlier in the year. They speculated that the shift in time of peak discharge (30 days over the last 50 years for one river or from April 10 to March 11) was due to timber harvesting and increased snow exposure to solar radiation. This shift in peak discharge could have major implications for fry emergence and for smolts that tend to migrate in response to peak flows.

Future change in the peak flow hydrograph was predicted through analysis of historic flows and predicted climate change on the Fraser River watershed (Morrison 2002). Peak flows would be 24 days earlier and date of peak more variable (13% of the years peak flow would occur later as a result of summer rain). Unlike the McIntosh (1994) study that found no change in peak flow magnitude, Morrison (2002 estimated that global warming would decrease average peak flow by 18%. Both juvenile and adult run timing in the Fraser River could be affected.

Water Quality

Changes to water quality can occur in interior systems following road building and harvesting. After forest harvesting at Slim Creek, an increase in orthophosphate concentrations, an increase of 2-3 times the total phosphate concentration, and 5 times the nitrate concentration were recorded (Brownlee et al.1988). Suspended sediments increased 4-12 times. Roads were considered the main source of sediments and not skid-trails. Likens and Bormann (1974) examined the application of inorganic fertilizers on eastern forests. They felt the long term effects were unknown, but in the short term there were no effects on water quality unless fertilizer was inadvertent applied directly to streams or lakes. The addition of nutrients might prove very detrimental for small isolated ponds and flood channel pockets where juvenile fish might reside through the summer months. Increases in nutrients could enhance algae growth, decrease oxygen levels, and result in fish suffocation in the confined habitats.

An increase in erosion and mass wasting can occur following road construction and forest harvest (Forman and Alexander 1998; Gucinski et al. 2001). In Kootenay Lake, B.C., sedimentation rate (measured by lake-cores) appeared to be associated with road construction and logging (Macdonald et al. 1994). Sediment and organic materials are mobilized during peak snowmelt discharge and are deposited in deeper pools and the interstitial substrate spaces. These are the prime over-wintering habitats of interior salmonids (Hillman et al. 1987; Steward and Bjornn 1989; Johnson and Kucera 1984). The in-filling of deeper pools represents a loss in habitat as they are more likely to contain water during summer dry periods and less likely to completely freeze during winter. A reduction in substrate quality has been cited as a reason for juvenile salmon migration (Hillman et al. 1987; Bjornn 1971).

Riparian Zone

The critical pathways of human influence on channel-water temperature are; modification of riparian vegetation structure, human alteration of groundwater dynamics, and structural changes to channel morphology (Poole and Berman, submitted). Streamside timber harvest in the interior of B.C.

has caused large increases in summer water temperatures. Small tributaries of Slim Creek warmed 1.5 to 5^0C as they flowed through clearcuts of approximately 1 km in length (Brownlee et al. 1988). A 2-6^0C increase in temperature for a similar length of exposed stream along the Middle River (Takla Lake) was anticipated (Scrivener and Andersen 1994). Stream temperature is directly proportional to heat input (radiation and exposed surface area) and is inversely proportional to stream discharge (Marcus 1990). Small side-channels, flood-channels and flooded lands are more likely to exhibit increases in water temperatures due to thermal loading (shallower, slower moving water) than the main channels of flooding streams..

The role of groundwater in modifying stream temperatures and the processes by which it occurs have only recently been studied in detail (Poole and Berman, submitted). Channel water temperature trends away from the "baseline" temperatures often associated with tempered groundwater and moves towards atmospheric temperatures as it travels downstream. In Carnation Creek water temperatures in the gravel were cooler in the summer and warmer in the winter than corresponding temperatures in the stream (Hartman and Leahy 1983). Groundwater is a source of cool water in summer and may provide a thermal refuge for salmonids (Levings et al. 1985). In winter isolated ponds that are modified by groundwater are often warmer than the main-channels, thus providing an excellent over-wintering site for juvenile salmonids (Bustard 1986; Swales and Levings 1989). The impact of interior forest practices on groundwater sources has not been documented, but is being examined in the Stuart-Takla River (Macdonald 1994) and the role of groundwater as fish habitat is being studied in the Coldwater River (S. Bennett, personal communication). Protection of groundwater is complicated as groundwater distribution pathways are hard to identify and recharge areas may be remote from discharges (Power et al. 1999).

In northern interior streams, water temperature remains below 1^0C from the end of October to mid-April (Scrivener and Andersen 1994). Northern streams are subjected to frazil ice, anchor ice and frost penetration up to 1 m into the gravel (Blachut 1988). Riparian vegetation can reduce heat loss to the atmosphere during winter. The exposure of channels and isolated ponds to atmospheric conditions may increase the degree of ice formation in winter. The riparian canopy reduces air movement above the surface waters and increases long wave radiation. Snow usually covers northern interior streams and insulates them from extreme cold (Macdonald et al. 1992). When riparian vegetation is removed insulating snow can blow off of the stream's ice surface and shallow channels could freeze. This would prove detrimental to both fish eggs and fish trapped in shallow pools in winter.

The riparian tree canopy reduces exposure of rearing fish to solar ultraviolet radiation (UVR). Small, shallow, clear streams and lake margins would be very susceptible to the harmful effects of UVR following the removal of trees in the riparian zone. Cover seeking behaviour and avoidance of UVR has been demonstrated for coho alevins and two-month-old coho fry (Kelly and Bothwell 2002a) and for invertebrates, especially grazers (Kelly and Bothwell 2002b). This behaviour was apparent on midsummer, cloudless days and was not apparent under lower solar intensities (cloudy skies). Current research indicates that an increase in ultraviolet radiation can reduce photosynthesis (growth of algae) and can inhibit benthic invertebrates such as larval chironomids and diptera (Bothwell et al. 1994; Kelly et al. 2001). The avoidance of UVR by salmonids and invertebrates may be a one of the reasons for the strong nocturnal behaviour noted by juvenile in interior lakes and rivers.

Cumulative Effects of Interior Forest Practices

Cumulative effects of forest practices on watersheds are difficult to quantify (Reid 1993) and the cumulative effects on off-channel habitats have never been evaluated. A survey of central interior British Columbia streams (Chatwin et al. 2001) recorded and defined stream damage due to forestry and ranching activities. All of the streams were small. Of 25 streams that had channel disturbance, the causal agent was equally distributed between harvesting, wind-throw, and livestock damage. Also 26 streams had moderate to high loss of canopy shade due to forest harvesting (mainly clearcut). Sedimentation from exposed rootstocks was the most likely factor damaging the stream in the case of wind-throw.

Summary of Forestry Impacts

Coastal Forestry

- Forest harvesting and road construction can increase total annual water yield, increase peak flow magnitude, and reduce time to peak. The first autumn storms may show the greatest increase in peak flow.
- B.C.'s coastal watersheds may be very sensitive to forest harvesting because of their shallow soils and steep terrain.
- Hydrological changes may influence the access to floodplain sites and distribution of winter rearing fish.
- Small ephemeral floodplain sites are vulnerable to disturbance. The muck veneer is easily eroded and semi-aquatic vegetation can be damaged by changes in water depth, light-levels and nutrient concentrations. Removal of riparian vegetation can influence temperature, allochthonous pathway, woody debris input, and streambank integrity. Refuge in the form of woody debris, semi-aquatic vegetation, and pool depth can be lost.

Interior Forestry

- The processes by which snow accumulates in openings and snow melts, is important in understanding the effects of forest harvest on the hydrology of interior watersheds.
- In smaller watersheds, total water yield and flood magnitude can increase following harvest. In large watersheds where 5-25% of the basin is impacted, changes in storm discharge regimes are not definitive. Large basins buffer the impact of smaller localized changes in snowmelt processes due to forestry activities.
- Rain-on-snow events following harvest may produce an increase in magnitude of peak flood. However, if a considerable volume of snow is held within the forest canopy, a rain-on-snow event will exhibit a larger storm discharge from a forested area.
- The role of interior forestry in altering; ground water sources, ice formation, interstitial spaces in the substrate, and riparian functions should be considered.
- The role of UVR in modifying invertebrate and fish behaviours may be critical in interior rivers and lakes. Maximum flooding, fish use of shallow waters, and UVR levels are all highest during the same period of time.

Impacts of Urban Development and Agriculture

Hydromodification

The most dramatic changes to the pattern of flooding on a floodplain and most serious losses of floodplain fish habitats are due to urban development. In a review of urbanization and its impact on fish habitat (Imhof et al. 1991), the process of modification was characterized as a continuum of change from pristine conditions to extreme degradation. Human activities cannot be sustained where serious damage from flooding can be expected. Thus measures to prevent flooding are often undertaken and in doing so the floodplain ecosystem is destroyed. In a developed floodplain, social pressures exceed environment concerns and few viable options to maintain or regain lost fish habitats are available. On an undeveloped floodplain, consideration can be given to limiting activities to those that are consistent with maintaining natural systems.

The Fraser River floodplain covers only 2.8% of the Fraser Basin (Langer et al. 2000), yet over 50% of the population of B.C. live there (Moore 1990). In order to protect the high human values associated with lowland development from flooding, considerable hydromodification (dyking, dredging, ditching and land filling) has occurred. These activities are designed to control the natural instability of rivers, seasonal floods, and channel migration (Booth 1991). Unfortunately, they also disconnect channel fluvial and biological systems from floodplain processes. Langer et al. (2000) considered the Fraser River to be almost completely and permanently separated from its floodplain and the riparian zone had been eliminated due to a lack of setbacks. The lower Fraser River is now constrained within its banks by 620 km of dykes and an estimated 70% of the wetland habitats have been isolated (Birtwell et al. 1988).

Although the area of wetlands lost can be estimated, the loss of historic fish habitat associated with these wetlands is extremely hard to quantify. In 1924, Sumas Lake, was drained and converted into farmland. This historic Fraser Valley lake was tidally influenced and during spring floods it increased to approximately three times its minimum size. The lake seasonally ranged from 10-25 km in length, 6-10 km in width, and 3-10 m in depth (Chilliwack Museum. 2002; Stolo Internet 2000). The total lake area was estimated to be 11,600 ha and this was comprised of 3,600 ha of open water and another 8,000 ha of surrounding marshland and sloughs (Moore 1990). No measurements exist of salmon abundance, prior to drainage. If salmonid abundance ranged from 20 coho smolts / ha for an open coastal lake system (Beechie et al. 1994) to an estimate of 2,000 salmonids / ha in spring from a marsh (Wetlands Network News 1996). The number of juvenile salmonids that once reared in 11,600 ha of Sumas Lake would have ranged from 230,000 to 23,000,000.

Levings and Thom (1994) indicated that there have been large net losses of vegetated habitats (swamps and floodplain forests) and estimated that eleven major deltas in Puget Sound have suffered wetland losses totalling 47% of their area since the mid-1800s. Schmitt et al. (1994) estimated the losses as 18% for Strait of Georgia and 58% for Puget Sound. The development of the Fraser River delta has alienated; 70% of the salt marsh, 30% of the tidal freshwater marsh, and 99% of the seasonally flooded habitats (Birtwell et al.1987a; Langer et al. 2000). This loss was attributed to the extensive dyking for land reclamation and flood control. In the Fraser Estuary an estimated 70 to 90% of estuarine habitats have been lost (Levings 2000). In the lower Pitt River most of the fen and bog habitats have been isolated from the main river and some have been converted into agricultural lands (B. Clark, personal communication).

Birtwell et al. (1988) examined the impacts of hydromodification on the lower Fraser River. They estimated that historically the Fraser River annually flooded 20,570 ha of wetlands compared to 6,425 ha in 1988. Approximately 80% of the Fraser River delta wetlands have been converted to other uses (primarily agriculture). Birtwell et al. (1988) indicated that dyking impaired migration of adults and fry into tributaries from the mainstream Fraser and pumps caused mortality to downstream migrating smolts. Spoil from dredging can in-fill marshes and suction dredges can kill salmon fry (Tutty 1967). Wetland habitats have been alienated due to dumping of rubble and garbage, landfills for ports, housing developments, and road construction (Birtwell et al. 1988). The most practical means of protecting a wetland is to surround it with a wetland buffer (Castelle et al. 1992). This would reduce adverse impacts to wetland functions from adjacent developments, moderate the effects of stormwater runoff, stabilize soil to prevent erosion, filter suspended solids and nutrients, remove toxic substances, and moderate water level fluctuations.

Specific parts of the Fraser Delta have been studied for loss of salmon rearing habitat (Levings et al. 1996). In 1880 the river flooded 2,896 ha of a riverine tidal wetland complex on the North Arm of the Fraser River. These wetlands were accessible to fish. This area was reduced to 109-ha by 1940. China Creek estuary and wetlands in the eastern basin of False Creek were filled in for industrial purposes by 1915 (Levings et al. 1996). Habitat losses are still ongoing (Langer et al. 2000), mainly to the subtidal and mud-sandflats (Levings et al. 1996)

The lower Salmon River that flows into the Fraser River at Fort Langley has undergone considerable modification for urban and flood control purposes (Giannico 1995). The lower reaches of the Salmon River and its small tributaries have been dyked, channelized, and straightened into a network of ditches to improve drainage and prevent agricultural land from flooding. The dredging may have altered off-channel winter habitats (Henderson 1991). The mouth of the river and some tributaries have been gated to prevent flooding during Fraser River peak snowmelt discharge. A pump is operated from March to July causing consideration juvenile salmon out-migration mortality (25-31%, Paish and Associates 1981). Historically these areas were large seasonally flooded wetlands (Giannico 1995). Natural vegetation consisted of prairie grass, shrubs, willow and hardhack.

At present, about half of the approximately 300 significant salmon spawning streams in the Fraser River system flow through the urbanized area of the lower Fraser Valley. These streams represent 65% of the basins coho production (Langer et al. 2000). Langer et al. (2000) cited a loss of 2,000 km of historic streams in the Greater Vancouver area of which 588 km have been culverted and covered. Salmon habitats are under threat from rapid urbanization and rapidly growing agrobusiness (Hall and Schreier 1995). Langer et al. (2000) noted it was ironic that most of the Fraser Valley floodplain streams flow in part through agricultural reserve lands and these provide an important buffer, keeping urban development at bay. In the Fraser Valley a few remnant salmon populations have been re-established in streams such as Bridal Falls Creek that were lost to railway building, farming and urban sprawl (Glavin 1997).

The desire to constrain B.C. rivers within defined channels and reduce flooding is not limited to the lower mainland. Habitat problems associated with hydromodification exist in the Thompson River Basin, tributaries of the Fraser River below Hope, Nicola River Valley, the east coast of Vancouver Island, and in general near most B.C. towns and cities bordering a water course. The interior of B.C is a region of high elevation plateau's and mountains with only a few narrow, relatively flat floodplains. Settlement in the interior has been located on these floodplains causing extensive pressure on the rivers.

Channel modification measures in more rural areas may be limited to channelization and placement of course rocks (rip-rap) along the margins of the channel to reduce erosion and prevent flooding. The interstitial spaces within rip-rap are used in winter by juvenile fish (Swales et al. 1986; Levings and Lauzier 1991; M. Crowe, personal comunication) and can provide sanctuary for 10 juvenile coho / linear meter (Sheng et al. 1990). However, rip-rap does not provide the intricate habitats required by multiple age classes and species of fish. Rip-rap also impedes lateral stream migrate (Schmetterling et al. 2001). The future loss of complex habitats associated with reduced avulsion (lack of channel migration) is speculative.

One of the few studies to estimate the loss of coho habitat associated with human activities on a large coastal basin was completed on the Skagit River, Washington (Beechie et al. 1994). The major loss of coho rearing habitat (91% of total winter loss) was associated with dyking, ditching, and dredging for agricultural and urban land protection. They estimated a 34% loss of winter habitat and a 24% loss of summer rearing habitat. This loss was attributed to the removal or isolation of 41% of the side-channel sloughs, 31% of the small tributaries, and 29% of the "distributary" sloughs. The largest loss of winter habitats was associated with side-channel and distributary sloughs located in the floodplain and delta areas of the Skagit River.

Extensive ditching and wetland drainage has occurred in the lower half of the Black Creek watershed on Vancouver Island. In 1994, 16% of the basin was cleared for agriculture use and 88-km of ditches (42% of the total drainage network) were constructed (Brown et al. 1996). It was estimated that 47-50% of the historic wetlands had been drained mainly for agricultural purposes. The remaining wetlands flood in winter and hold adequate water in summer. They represent 2/3 of the coho summer rearing habitat (Brown et al. 1999). The lower half of watershed which in winter contained flooded fields, ditches, swamps and intermittent tributaries (many now channelized) reared 75% of the coho smolts through the winter (Brown et al. 1999).

The relationship between habitat use and adaptive fish behaviour is an important issue (I. Birtwell, personal communication). Fish may have occupied historic habitats that have favoured "group" survival over time, but human development has imposed changes such that these habitats are now sub-optimal. Will the fish continue to try to use these poor habitats or will they exploit other options? Fish behaviour can not adapt in the short term and it is unlikely behaviour patterns will change. The fish will continue to occupy these sub-optimal habitats. Thus, the considerable changes to habitat and natural process that have taken place during the human development of floodplains will reduce fish survival, in part because habitats have been eliminated, but also because ingrained fish behaviours can not change fast enough.

Flow Control and Reservoirs

The relationships between fish production, floodplains, and natural flow regimes has been recognised for large world rivers (Marmulla 2001; Welcome 1979). The impact of impoundments on fisheries values has been well documented in B.C. (Hirst 1991; Mundie and Bell-Irving 1986; Mundie 1991; Burt and Mundie 1986), although the importance of maintaining natural hydrographs does not appear as a dominant theme. The Provincial Government has adopted a Habitat-Flow methodology described as a "modified Tennant method" and considerable effort is spent in establishing summer low flow criteria based on mean annual discharge for specific coastal rivers (e.g. Courtenay River; Riddel and Bryden 1996). High autumn and winter flows are considered eligible for storage on the B.C. coast. In the interior of B.C., spring/summer snow-melt peak flows are considered eligible for storage.

In B.C. many dams and weirs are operated for hydropower generation and for flood prevention. Changes to the natural hydrograph have occurred and often the timing of water releases are designed to assist the movement of spawning salmon or to maintain adequate summer rearing flows. Late summer water releases in the Nechako River are designed to assist the spawning migration of sockeye salmon into its tributary, the Stuart River (Rood and Hamilton 1995b). In the Puntledge River, summer flows are augmented by water collected through the winter (Hirst 1991). These releases maintain summer rearing habitats and facilitate upstream migrations of summer chinook and steelhead trout.

The potential impacts to the fisheries resource of changing the natural hydrograph are difficult to measure and habitat changes often take decades to develop. The practice of reducing peak floods (storage in reservoirs) and augmenting minimum river flows has the potential to change the physical structure of downstream reaches, reduce the rate of river avulsion, and increase levels of fines within substrate. Reduced peak flows and augmented summer flows are followed by changes in downstream rivers leading to a different succession of herbaceous trees within wooded wetlands (Toner and Keddy 1997). In the interior of B.C., flow stabilization resulted in channel stabilization (channel fixed in position) and diminished deciduous shrubs (reduced cottonwood recruitment) along the lower Kootenay River (Polzin and Rood 2000). The elimination of large floods that flush fines from the gravel can impact on spawning grounds (Mundie 1991). The quantity and quality of aquatic habitats and characteristics of riverine swamps can be manipulated by controlling the timing and magnitude of the flood pulse, accessibility of different watercourses, and internal paths of water flow through the swamp (Sabo et al. 1999). Flow control has the potential to alter off-channel migrations of juvenile fish. The magnitude of the first autumn freshets in coastal B.C. streams is important in establishing the use of specific off-channel sites by juvenile coho (Brown and Hartman 1988). If reservoirs are accessible to salmonids, fish rearing in the littoral zone may be subjected to altered lake-levels that are seasonally unnatural.

Rapid changes in flow from hydro dams that are used as peaking facilities can be damaging for fish. In 1992 a forced spill on the Bridge River caused juvenile salmon to move into areas that were previously de-watered (Higgins and Bradford 1996). An estimated 18,000 fish were salvaged from side channels and depressions in the floodplain during and after the rampdown. In 1975, the stranding of fish associated with a rapid decline in discharge was monitored as part of the proposed power plant expansion of the John Hart Dam on the Campbell River (Hamilton and Buell 1976). Following a rapid decline in discharge, the stranding of salmonids was not evident in the steeper banked, higher gradient reaches of the river. However, in the shallow banked, low gradient reaches of the lower river, so many stranded coho and chinook juveniles were observed that the flow had to be raised before the study could be completed.

Rainbow trout may be less susceptible to displacement during flow releases than salmon. Controlled release of dammed water designed to produce a flushing flow below a Wyoming tailwater, did not displace juvenile rainbow trout but, a small number of radio-tagged adults did move upstream (Simpkins and Hubert 2000). A five-fold increase in discharge occurring twice daily in artificial channels had little effect on rainbow trout fry (Irvine 1987).

Transportation Corridors

Highways and rail systems constructed on floodplains tend to fix the channel into a specific location at a bridge or culvert crossing and this reduces stream migration across a floodplain (avulsion). This reduces the opportunity of a river to create new channels and off-channel habitats. The construction of a transportation corridor can also block access to off-channel sites during flood events. Properly engineered structures to pass fish are required. When transportation corridors are abandoned the fish may return. The Kettle Valley Railway, paralleling the Coldwater River, has been abandoned for decades. Remnant channels and portions of the floodway that were alienated by the rail-bed are now being reclaimed by the river (M. Crowe personal communication).

The early construction of the CNR rail system and later highway along the Skeena and Buckley valley bottoms has cut off floodplain habitats. The condition of culverts is currently being surveyed and the possibility of reconnecting ox-bow ponds and backchannels is being examined (T. Pendray and M. Drewes, personal communication). CNR tracking along the N. Thompson Rivers has encroached on the river and has often required riverbank modification (Whelen and Lister 1985a,b). Following construction, herbicides are often used to control weeds along transportation corridors, but buffer lands adjacent to the encroached upon rivers may not be available. Roadside ditch cleaning removes rooted vegetation and exposes soils to erosion. This may result in high sediment loads entering into streams and rivers from the ditches.

Culverts and stream crossings are integral components of drainage networks. The proper design, installation, and understanding of biological effects of engineered structures is essential for maintenance of fish migration (Anderson and Bryant 1980). Engineered structures designed solely for migrating adult salmon (Dane 1978) may not be adequate to facilitate access to winter floodplain habitats by small fish. The swimming ability of salmonids is size dependent (Reiser and Bjornn 1979). The ability of migrating juvenile salmonids to overcome a barrier is dependent upon the size of the migrating fish and nature of the barrier. Small fry (35-50 mm) in spring and juvenile fish in autumn (70-100 mm) can be prevented from moving between habitats by a barrier 3 to 5 times higher than their fork-length (Symons 1978).

The extent of floodplain habitat loss that is directly associated with transportation corridors is difficult to measure. Beechie et al. (1994) estimated 9% of summer coho habitat and 3% of winter coho habitat on the Skagit River was lost due to inadequate culverts (blocking access). They felt that habitats lost due to bad culvert design were very specific problems that could be dealt with easier than other major losses in floodplain habitats associated with hydromodification.

Runoff from Urban Development

Urban Hydrology

Urbanization has the greatest impact per unit area on the hydrological regime (MacKenzie 1987). MacKenzie (1987) described the urban hydrological regime and listed these impacts: modification of local climate, increased flooding potential, reduced water quality, increased erosion, and increased sedimentation. The hydrograph is altered as surface permeability is reduced due to streets, parking lots and closely spaced buildings. This increase in impervious surfaces results in a larger proportion of rainfall reaching the channels as surface runoff (Lucchetti and Fuerstenberg 1993). The hydrograph peaks faster due to rapid runoff from impervious surfaces and more hydraulically efficient drainage networks. Roadside ditches rapidly carry surface water directly into streams. The impervious road surfaces create more rapid runoff during both rain and snowmelt events (Forman and Alexander 1998). Roads also convert slow-moving ground water into fast-moving surface water at cutbanks (Harr et al. 1975). Peak discharges are magnified, baseflows are reduced, and entirely new peak runoff events may be created (Booth 1991; Booth and Jackson 1997). Higher peak discharges, yields greater flooding, restructures riparian zones and alters channel morphology.

Increased runoff is usually associated with increased stream discharge rates, changes in channel morphology, increased erosion and increased sediment concentrations. In contrast to the high concentration of sediments produced from many urban streams, some urban channels and ditches have been scoured and contain less fine material and slightly higher values of intragravel dissolved oxygen (Finkenbine et al. 2000). This is attributed to the higher peak flows generated by impervious areas and the reduced recruitment of fine material from the modified banks found in these urban watersheds.

Continued urbanization causing increased runoff may generate increased flooding problems in the future. Comparison of Nicomekl (more urbanized) and Salmon rivers (more agricultural) indicated that a slight increases in runoff rate could lead to increased flooding problems (Leith and Whitfield 2000). Using a hydrologic simulation program, Booth (1991) estimated a change in impervious area from 6 to 29% would double the magnitude of most peak runoff events and would create several high flow events that would not have normally been evident. Langer et al. (2000) cites four streams in the lower Fraser Valley with 23-33% of the watershed under impervious surfaces. Stormwater runoff is a concern in basins where roads and airports comprise 20% of the surface area, as in the Fraser Delta region (Rood and Hamilton 1994).

On the East Coast of Vancouver Island the percentage of impervious area was calculated for 14 watersheds (Reid et al. 1999). A steam quality index was used to rate the watersheds based on percentage of the watershed covered by impervious surface. These categories where; 1-4% minimum impact, 5-10% stressed, 11-25% impacted, and 26-100% degraded. The amount of impervious surface ranged from 0 to 20%, averaged 8%, four watersheds were considered impacted, four were rated as stressed, and six were minimally impacted. Reid et al. (1999) considered 155 of 165 streams to have summer low flow problems.

Horner et al. (1995) stated that "the effects of modified hydrology accompanying urbanization exert the earliest and, at least initially, the strongest deleterious influences on the freshwater ecosystems studied". The steepest decline in biological function occurred as urbanization increased impervious land cover from 0 to approximately 6%. The increase in flood frequency, flood magnitude, and changes in habitat structure associated with urbanization, are linked to declines in salmon populations (Moscrip and Montgomery 1997). Changes in species composition may follow urbanization. Coho salmon dominate cutthroat trout in many rural watersheds, while the advantage shifts to cutthroat as the watershed is urbanized (Horner et al.1995). Coho become less abundant relative to cutthroat trout (Booth 1991). Urban streams tend to be channelized, culverted, lack riparian vegetation, and have modified banks. Flow is constrained and laminar, pools are lacking, as are the complex edge and microhabitat refuge considered important to salmonids (Bilby and Bisson 1992; Bisson et al. 1988; MacMahon and Hartman 1989).

Water Quality of Stormwater

In this paper I will not attempt to list all possible pollutants or all possible papers on urban and agricultural runoff. Considerable information is available on the Internet through the Fraser River Action Plan (1998). Waldichuk (1991) lists and describes aquatic contaminants from many different sources (e.g. 11 coastal pulpmills, mines and agriculture). A number of bibliographies have compiled references on the environmental quality of the Fraser River basin. These include a major bibliography comprising over 350 entries on water quality and habitat loss (Stapleford 1995) and over 5000 references on environmental quality (Missler 1992, 1994). MacKenzie (1987) lists pollutants in a review paper on runoff. Ferguson and Hall (1979) list typical constituents of urban runoff and describe in detail 21 major studies and their findings. Levels of 20 major contaminants from selected urban runoff sources are assessed and quantified for the lower Fraser Basin (Stanley Associates Engineering Ltd. 1992). UMA Engineering Ltd (1994) lists 252 storm discharge outfalls in the Fraser River Estuary downstream of Kanaka Creek and describes sampling sites and water quality test parameters. Hagen (1992) in a background paper, examined major and minor sources of contaminants to the Fraser River estuary and described legislation, programs, and best management practices.

Urban lands contribute considerable runoff, effluents, and industrial pollutants to stream systems. Buildings and paved and compacted surfaces do not allow water to percolate into the soil. Rainwater along with dust, oil, animal faeces, and chemicals are funnelled into storm sewers and directly enter watercourses. Elevated levels of polycyclic aromatic hydrocarbons (PAH) produced from fossil fuel combustion and polychlorinated biphenyls (PCB) used in electrical equipment, have been found in fish and sediments in the lower Fraser River and the Thompson River near Kamloops (Fraser River Action Plan 1998). There is evidence of sewage pollution in both the Thompson and the North Thompson rivers as well as petroleum hydrocarbons in Thompson and South Thompson River fish and water samples (Rogers and Mahood 1983). During heavy rains, flooding can overload sewer systems creating what has been termed a "combined sewer overflow" (Fraser River Action Plan, 1998).

Heavy rainfall and flooding will increase the levels of faecal coliforms, metal concentrations (copper, zinc, lead, and manganese), PAH, and hydrocarbons. These contaminants are associated with urban runoff. An increasing amount of pollution is being attributed to urban runoff and in the future it will far exceed municipal sewage and industrial waste as a source (Fraser River Action Plan, 1998). Vehicle traffic is increasing, more surfaces are paved and more buildings erected, while sewage treatment plants are being upgraded and harmful chemicals from the forest industry are being reduced. Chemical transport from road surfaces occurs primarily in stormwater runoff. The two major categories of pollutants are de-icing salts and heavy metals (Forman and Alexander 1998). The two primary de-icing agents are NaCl and Calcium magnesium acetate (CMA). CMA is less toxic to aquatic organisms and is a more effective deicer.

Ferguson and Hall (1979) examined over 100 stormwater discharges and 12 combined sewer/stormwater overflows in the lower Fraser River-Estuary. The major pollutants in stormwater included fertilizers, pesticides, animal fecal matter, and surface accumulations of dust and dirt. They believed that stormwater contributed significantly to the overall pollutant loading. Natural water courses were utilized for stormwater transport wherever possible. Coquitlam and Burnaby use conventional sub-surface collection systems, while Surrey, Delta, Richmond, Maple Ridge, Pitt Meadows, and Port Coquitlam use ditches. In the Fraser Valley over 70% of the storm sewer discharges is influenced by tidal reversal and magnitude of Fraser River discharge. The major tributaries that receive stormwaters are; Brunette River, Coquitlam River, Pitt River, N. and S. Allouette Rivers, Kanaka Creek, Salmon River, Yorkson Creek, and Still Creek.

Drinnan et al. (1995) examined 12 tributaries discharging into Saanich Inlet (Victoria) for nutrients, fecal coliform, metals, chlorinated hydrocarbons (pesticides) and PAH. They attributed the high nitrogen concentrations in one stream to urea used as an aircraft de-icing agent. They described the two major anthropogenic sources of nitrogen, septic fields and agricultural lands, and estimated a 10kg N-nitrate/ha/year loss from agricultural lands. Several streams exceeded criteria for metal concentrations (copper, mercury, lead and zinc). Drinnan et al. (1995) speculated that the possible sources of the heavy metals were from marine-based activities, storm-drain runoff, and from a residual landfill.

Over the course of a storm event the concentrations of the various contaminants changes. An estimated 75-95% of street surface contaminants are removed during the first 30 minutes of a storm (Ferguson and Hall 1979). Singleton (1980) concluded, "after dry weather periods, high concentrations of pollutants discharged during the first flush may be detrimental to aquatic biota in the lower Fraser River and estuary." In Ontario a rain event of > 20mm resulted in elevated *E. coli* counts of lake bathing areas within 6 hrs of the onset of the rain event (Mattson et al. 2000). Typical stormwater immediately following a rain has a non-filterable residue concentration greater than untreated sanitary wastewater and a biological oxygen demand equal to secondary treated effluent (Ferguson and Hall 1979).

Our abilities to deal with urban stormwater and to comprehend the risks associated with urban development are questionable. The pollutants in surface runoff are difficult to control (Hall and Schreier 1995). Pollution problems occur over long periods, from non-point sources and are often not associated with individual runoff events; making cause and effect relationships difficult to study (Field and Pitt 1990). Coastal streams have low buffering capacity. When it rains there is a dilution effect due to the increase in runoff coupled with a soil water contribution of weak acids. In Kanaka Creek pH values similar to B.C rainfall (4.7-5.5) occur mainly from rainfall and urbanization (Whitfield et al. 1993). Municipalities in B.C. have ineffective or non-existent programs to deal with the quantity and quality of stormwaters (Rood and Hamilton 1994,1995a; Langer et al. 2000). Also, it was perceived that agricultural waste disposal and manure pose a much higher risk to water quality than septic systems (Cavanagh and McDaniels 1997). This perception may be caused by the scarcity of documentation as to the potential risk to surface water bodies from septic systems and stormwater.

Urban landfills have the potential to release contaminants into rivers. Discharge and concentrations of contaminants are related to precipitation, the composition of materials in the fill, and landfill site characteristics. Landfill leachates have been characterized and listed for B.C. landfills (Atwater 1980). Common contaminants include organic solids, ammonia, sulphides, and iron. Leachate samples collected from four municipal landfills (Vancouver area) were toxic to rainbow trout as measured in static bioasssays (6.5 to 100% v/v, 96-h LC50; Singleton 1980). The acute toxicity of municipal landfill leachates persists for up to 13 years after the landfill is closed. The collection and treatment of leachates before their discharge has improved in B.C. since the 1980's (Crowther 1997).

Wood waste piles if located near streams and wetlands have the potential to discharge toxic effluents into fish habitat. The potential risks associated with heavy rainfall and flooding on wood waste sites located near juvenile salmon over-wintering habitat is considerable. Birtwell et al. (1988) reported that 90% of the wood waste sites located in the Fraser Valley were located adjacent to the Fraser River. Woodwaste leachates are toxic and 96-hr LC50.s for rainbow trout ranged from 0.48 to 4.0% v/v (Singleton 1980).

Runoff from Agriculture

Drainage and Ditching

In a publication by Agriculture Canada, an entire chapter was devoted to managing "excess" water (Coote and Gregorich 2002). The underling assumption being that natural flooding is a problem to be corrected by ditching to "improve" lands. This may be true for conversion of wetlands to agricultural production but from a fisheries perspective the draining of wetlands through channelization and ditching represents a loss of fish habitat (Swales 1982; Hogan 1987). The role of wetlands as seasonal fish habitat, flood buffer, and in seasonal flow augmentation is lost through drainage. Certain crops such as cranberries grow best on lands that were once seasonally flooded peat lands. The dyking, ditching, and conversion of these lands has been to the detriment of fish habitat (Nener and Brock 2001).

Wetlands and natural channels function differently from ditches and drained lands. Choate (1972) indicated that wetlands are drained in two ways: directly through stream channelization and indirectly when cross-ditches and tiles are used to take advantage of improved downstream outlets. In Minnesota "undrained and poorly drained depressions were originally occupied by highly productive shallow lakes and marshes. Although the number of these is unknown it must have been considerable" (Choate 1972). A similar process of development is occurring in B.C.

Natural streams are not straight channels. Low gradient streams associated with floodplains meander back and forth. Sinuosity and wetted area are significantly reduced following channelization and a loss of stream length can occur (Chapman and Knudsen 1980). A straight ditch may be one-half or one-third as long as the original stream (Funk and Ruhr 1971). The loss of original stream length for three sections of channelized (straightened) stream were; 26, 36, and 52% (Huet and Timmermans 1976)

During channelization, woody debris and in-stream vegetation are removed. These elements redirect water creating pools and meanders and provide complex refuge for rearing salmonids during higher flows. Pools and backwaters are eliminated during channelization as a straight, homogenous sided, level bottomed, uniform gradient channel is created. This type of channel is not suitable for salmonid winter rearing when flows are higher (McMahon and Hartman 1989). The loss of fish habitat due to the elimination of "pool riffle character" may persist for more than 5 years (Cowx et al. 1986) and old ditches (> 50 years) may support healthier fish communities than ditches 6-8 years old (Headrick 1976). Channelization and stream bank stabilization eliminates complex edge habitat (Bisson et al. 1988) and constrains the flow making it laminar. This increases water velocity and erosive energy, which can create problems further downstream.

The hydrology of a wetland can be altered when drainage patterns are changed by ditching or water diversion (Choate 1972; Funk and Ruhr 1971; Hartman and Brown 1988). On the coast of B.C. summer low flows are reduced following ditching and in the interior winter flows can be reduced. Runoff is more rapid from culverted and ditched basins. This can increase the magnitude and shorten the duration of peak flows (Harr et al. 1975; Hewlett 1982; Jones and Grant 1996; Thomas and Megahan 1998). An increase in peak flow magnitude results in an increase in erosion and an increase in sediment loads during storm-events. In some cases banks may be stabilized with hard armouring (gabions, bin walls, rip-rap, retaining walls) and this could impede the upstream passage of fish. Conversely it was argued by Iritz et al. (1994) that a lower groundwater level may have a greater influence on peak flow formation than the increased channel conveyance capacity in the drained catchments. They noted this effect was larger after dry periods and peak flows could be increased by drainage following intensive rainstorms in catchments with an already high groundwater level.

The level of water is important for juvenile cutthroat trout and coho salmon. The higher the water level (deeper the pools) the more space is available to protect fish from predation and from water draw-down during dry periods. On the coast, the presence of standing water in winter and a high water table in summer is important for the existence of a wetland. Following channelization, Chapman and Knudsen (1980) recorded an immediate 97% reduction in annual salmonid biomass. However, they did not see a significantly decline in biomass of summer rearing coho within altered sections, except in the most severely altered reaches. In winter 95% less salmonid biomass was found in a channelized reach than in a control reach and this included losses of coho and older cutthroat trout. A game fish reduction of 40-70% and up to 90% (if water velocities were high) was attributed to channelization (Huet and Timmermans 1976).

A decrease in fish abundance and species diversity usually follows channelization (Luey and Adelman 1980). A deeply cut ditch may not have an adequate water level to facilitate movement of juvenile coho out of the ditch and into surrounding small drainages and seasonally flooded lands. These small drainages may simply pour into the main ditch and juvenile fish are unable to access these tributaries and find suitable winter habitat.

Water Quality from Farmlands

In 1988, approximately 190,000-ha of Fraser Valley land was agricultural (35,000 ha for animal husbandry and 155,000 for forage and crops; Birtwell et al. 1988). These are private lands and most are in the valley bottoms adjacent to water bodies. Agricultural activities are a key non-point source of pollutants (Hagen 1990). Runoff from agricultural areas includes; nutrients (manure and fertilizers), sediments, and pesticides and their residues.

Flooding and high rainfall can aggravate water quality problems or moderate them. In summer a large proportion of stream and ditch water is derived from groundwater. If the local aquifers are contaminated than summer flows will have high concentrations of pollutants and winter storm waters through dilution can have lower concentrations. However, heavy rains and flooding of agricultural lands can flush sediments, organic manure and agro-chemicals into local water systems. During peak flow in July 1993, Fraser River waters had an unusually high level of CO_2 derived from the decay of organic material and manure from flooded land (Cameron et al. 1995).

Surface runoff from fields increases with increased grazing intensity and percentage of bare soil (Jong and Kachanoski 1987). If overbank flooding occurs in spring prior to the establishment of a crop cover, massive sediment transport can occur. A common practise in the interior of B.C. is the spreading of manure on top of the snow and frozen ground in winter (M. Crowe, personal communication). It is possible that some of this manure will be carried into streams when the snow melts in the spring.

Bacteria numbers are generally elevated in runoff from manure-treated fields (Coote and Gregorich 2002). Fecal coliforms ranged from 42-709FC/100ml of water in the Sumas River and this was above provincial criteria (100FC/100ml) at 2 sites (IRC Integrated Resource Consultants Inc. 1994). Fecal coliform levels were eight times higher on wet days than on dry days. Water samples taken in the Matsqui Slough during winter had fecal coliform counts above acceptable levels for drinking and irrigation water (Top et al. 1997). This drainage supports intensive dairy, hog and poultry farming. In one Ontario case study (Thornley and Bos 1985), the effluent from underground systems yielded bacterial and chemical characteristics comparable to domestic sewage. This watershed contained more than 300 livestock farms in a 90-square-mile area.

Considerable nutrient loading of surface waters occurs in agricultural areas. Animal manure and chemical fertilizers are the largest contributors of nitrate-N to both the groundwater and surface water systems (Vizcarra et al. 1997; Hagen 1990). There is a significant direct relationship between the export of inorganic nitrogen (NO_3^- and NH_4^+) in a stream and percentage of its watershed in agricultural usage (Hagen 1990). In B.C., high phosphorus outputs are closely related to the percentage of the watershed in urban usage, as they are associated with sewage and septic fields (Hagen 1990). However, Becher et al. (2000) calculated that manure and chemical fertilizers represented 99.9% of the total phosphorus input into the Mississippi River from Iowa farmlands. Phosphorus enrichment due to runoff can lead to eutrophication of rivers and lakes.

There is considerable concern about the rapid rise in nitrogen levels found within Fraser Valley aquifers and streams. The "Canadian Drinking Water Guidelines" recommend N levels of < 10 mg/L (IRC Integrated Resource Consultants Inc. 1994). Berka et al. (2001) indicated that in summer nitrate contaminated groundwater dominated streamflow, while in winter surface runoffs contributed ammonia, phosphate and higher coliform levels. Nitrogen concentration in groundwater has changed from undetectable in 1971 to an average of 6 mg/L in 1991, for the lower Fraser basin (Vizcarra et al. 1997). The central Fraser Valley had levels ranging from 4-14 mg/L. Although some measurements were above Canadian guideline levels they were considered within the acceptable range by Vizcarra et al. 1997. In the Salmon River, nitrate concentrations of (7.1 mg/L were associated with summer low flows when a large proportion of the water in the stream was derived from groundwater (Wernick et al. 1998). This may be due to the contamination of the aquifer with nitrate from agricultural activities. The Sumas River was found to have been nutrient enriched when winter nitrate concentrations ranged from 2-5 mg/L (IRC Integrated Resource Consultants Inc. 1994).

The amount and rate of nitrogen entering the drainage depends upon the type and concentration of agriculture activities. Zebarth et al. (1999) estimated a loss of 68 kg N/ha for Fraser Valley farmland. Higher N losses were attributed to "animal intensification" (more poultry, swine, and cows per ha) on a diminished agricultural land base. For the Sumas Prairie the amount of manure produced was estimated to be 262 L/ha/day on land utilized by livestock producers and 84% of the dairy farms used chemical fertilizers as well. (IRC Integrated Resource Consultants Inc. 1994). Berka et al. (2001) in one study estimated 120 kg N/ha losses a year and indicated that as animal densities increased higher losses were apparent. In the Matsqui Slough during the autumn and winter rainy season, oxygen levels were depleted, while nutrient concentrations and organic carbon were elevated (Top et al. 1997). The agriculturally impacted, downstream sites, had poor water quality when compared to the less impacted upper reaches.

The implications of nutrient loading to aquatic systems from agricultural runoff are debatable. We suspect that small additions may prove beneficial, while large concentrations would prove harmful. It is likely that any addition of nutrients will change the functioning of the ecosystem. This sentiment was embellished by Likens and Bormann (1974) who stated -- "The ecological implications of adding nutrients to aquatic ecosystems in large concentrations versus the same total input in smaller concentrations over longer periods are undoubtedly quite different…"

In both coastal and interior drainages the direct impact of cattle to streams is a concern. Giannico (1995) observed that farmers tended to restrict livestock access to the main channel of the Salmon River, yet cattle wading and trampling damage was common to small tributaries. He noted that entire reaches of small tributaries had riparian vegetation removed. In Black Creek, I have observed small intermittent tributaries (dry in summer) that have been tramped by cattle. These same small water-courses will support winter rearing coho juveniles. The trampling by cattle leads to increased soil erosion, loss of bank integrity, and high sediment loads to local streams. The first major storm event of the water year transports the largest quantity of suspended sediments. In a study of the Sumas River, (IRC Integrated Resource Consultants Inc. 1994) concentration of suspended solids was higher on rainy days (9-95 mg/L) than on clear days (10-23 mg/L). These sediments may carry a significant amount of the sediment-associated pesticide load (Bergamaschi et al. 2001).

The wood industry is the largest single user group of pesticides followed by the agricultural industry. In 1999, a total of 286 active ingredients were purchased (excludes domestic label products) of which 20 accounted for 95% of the pesticides used in B.C. Of the 8,102,384 kg of pesticide active ingredients purchased in 1999 by British Columbians, 86% were anti-microbial (wood preservatives and anti-sapstain chemicals), 4.9% insecticides, 4.1% hebicides, 3.3% fungicides (ENKON Environmental Limited 2001). The leading individual chemicals represented the following percentages; creosote 66.5%, chromated copper arsenate 11.4%, didecyl dimethyl ammonium chloride 3.8%, mineral oil 3.2%, pentachlorophenol 2.5%, borax 1.9%, and glyphosate 1.3%.

Permits are not required for pesticide application on private lands. Thus, the impact of agricultural chemicals on fish and fish habitat is often difficult to determine. Pesticide use is dependent upon the kind of animals produced or crops grown. In a survey of agricultural pesticide use (IRC Integrated Resource Consultants Inc. 1994) 58% of dairy, 42% of hog, 7% of poultry producers, and 84% of produce farms and nurseries used pesticides. Pesticides enter surface water directly through atmospheric deposition or in surface runoff often associated with heavy rains. Coote and Gregorich (2002) noted that agrochemicals are often detected in surface waters, but rarely exceed guidelines for drinking water. However, in waters taken from specific sources on the Fraser Valley floodplain they may exceed levels appropriate for drinking, irrigation, or for aquatic protection.

Contamination of surface waters by agrochemicals has been documented in the Fraser Basin. A report specific to the Fraser Basin (Tuominen et al. 1998) assessed the effects of contaminants on aquatic ecosystems. Ditches draining two Cranberry bogs, flowing into salmon bearing waterbodies in the lower Fraser Valley, had insecticides residues (Azinphos-methyl, "AZI" and parathion, "PAR") that adversely affected non-target aquatic organisms (Wan et al. 1995). Low levels of aerial drift were detected beyond the outer perimeter of application and the chemicals persisted for 72 and 32 days respectively (Wan et al. 1995). McLeay and Hall (1999) recorded concentrations of organophosphate (OP) insecticides high enough in summer to impact sensitive ditch and river invertebrate fish-food organisms within Nicomekl River drainage ditch outfalls. Dinoseb was consistently found in Nicomekl and Sumas River ditch water for one year after the spray season (Wan 1989). Groundwater samples from the Abbottsford Aquifer contained residues from synthetic pesticides, likely Telone (Szeto et al. 1994). They were present in trace amounts but persistent in soil and water and had caused significant groundwater contamination. Chemicals once used for mosquito control such as malathion had resulted in a fish kill within a small pond and direct application of Abate altered the composition of aquatic fauna (Wan and Wilson 1976). A study to assess concentrations of chlorinated organic contaminants in benthic insects, sediments and fish from the lower Fraser River (Richardson and Levings 1996) found the concentrations of most chemicals was below detection limits. Sculpins (*Cottus asper*) samples did contain the highest concentrations of phenolics.

Hagen (1990) examined the nature and magnitude of the agricultural waste sources in B.C. and described the recommended best management practices. Consideration was given to managing the timing of applications, types and amounts of waste. Coote and Gregorich (2002) examined current approaches to agricultural runoff and provided considerable information and references related directly to Canadian farming. Information on pesticide and herbicides used in B.C. is available through the Fraser River Action Plan on the Internet. Marcus et al. (1990) lists the lowest observed short-term toxicity and long-term chronic toxicity levels for a variety of toxicants that salmonids in interior rivers are likely to encounter. Wood (2001) listed various means of reducing the harmful impacts of manure and its application. In a review of factors limiting non-point source pollution from cropland, Dosskey (2001) described various methods used to abate water pollution. These included:

1. filter stream water
2. buffers that retain pollutants from runoff,
3. reduction of surface runoff from fields,
4. filter surface runoff from fields
5. filter groundwater runoff from fields
6. reduce bank erosion

Most of these water pollution abatement methods can be achieved through a healthy, stable riparian zone.

Interior Ranching and Farming

In the interior of British Columbia the major agricultural use of seasonally flooded lands is associated with livestock production. The interior range-lands extent in a corridor from the B.C - USA border at Osoyoos, through Kamloops, Williams Lake, Buckley Valley to slightly west of Prince George (Wikeem et al. 1993). Riparian zones and wetland meadows are important for forage and cattle grazing (Powell et al. 2000). Sedge forage on interior meadows can average from 560-6,000 kg/ha (Wikeem et al. 1993) and from wetland ranges from 1500-5000 kg/ha (Powell et al. 2000). It has been estimated that 65% of the total wetlands are suitable for hay production and pasture (van Ryswyk et al. 1992 cited in Powell et al. 2000). Cattle make disproportionate use of riparian zones and wetlands (Bryant 1982; Platts and Nelson 1985) and the use of river channels and floodplains by livestock in spring and summer is high relative to uplands (Smith et al. 1992). Powell et al. (2000) listed some of the major impacts to the stream environment when livestock graze on floodplains:

1. bank sloughing and shearing
2. soil trampling
3. excessive nutrient enrichments
4. reduced vegetation cover (riparian), higher water temperatures
5. channel characteristics altered (width, depth, substrate, sinuosity, riffle/pool ratio).

The impact of cattle grazing on fish habitats has been well documented (Jansen and Robertson 2001; Fitch and Adams 1998; Belsky et al. 1999; Kauffman et al. 1983; Kauffman and Krueger 1984; Platts 1991). However, most of this research has been conducted on lotic ecosystems (flowing streams) in dryer regions of the mid-western USA. Their findings should be interpreted with care. The interior of B.C. is slightly wetter and contains many seasonal small streams, small lakes, wetlands, flooded meadows, and groundwater channels.

In B.C. the largest portion of the Thompson River coho decline was attributed to agricultural land use and road density, but not to the proportion of land logged (Bradford and Irvine 2000). In The Nicola River Valley, high summer water temperatures limit salmon production and the high temperatures are linked to a loss of riparian vegetation along the river and its tributaries (Walthers and Nener 1997). In Montana, two agricultural tributaries (irrigated forage and livestock grazing) had the "largest estimated soil erosion and sediment delivery rates, the greatest habitat impairment from nonpoint source pollution, and the most impoverished macroinvertebrate communities" when compared to timber harvesting and wilderness tributaries (Rothrock et al. 1998).

Floods and freshets can accelerate stream damage on reaches with heavy grazing (Platts et al. 1985). Beeson and Doyle 1995, examined the river bends along Deadman Creek, Chase River, and Bonaparte River. River bends with reduced vegetation cover had five times more erosion during flood events than vegetated banks. "Major erosion" was 30 times more prevalent on non-vegetated bends. They recorded 700% more sediment entrapment over vegetated surfaces and noted that the length of the vegetation was important. Channels with vegetated banks were narrower, deeper and the banks were less steep (Millar and Quick 1993). Although bank failures occur naturally due to flooding and ice scour, removal of vegetation can accelerate this process. Uncontrolled grazing caused six times more "gross bank erosion" than on a protected control stream reach (Trimble 1994). The erroded banks were associated with stream widening. The difference in erosion was attributed to the breakdown of banks by trampling, not due to bank scour caused by vegetation removal. Average critical bank shear stress value calculated for riverbanks covered by well-developed rooted vegetation was three times that from rivers with weakly vegetated banks (Millar and Quick 1998).

Lentic ecosystems (marshes, lakes, wetlands, and flooded meadows) have been poorly studied in areas similar to B.C's interior (Powell et al. 2000). The flooded meadows and seasonal ponds, are the ecosystems that juvenile salmonids might temporarily occupy during spring-summer flooding. However, the presence, abundance and diversity of fish using such habitats is not well documented. The relationship between livestock grazing and forage production in seasonal flooded meadows and fish use has not been studied.

The production of forage crops in the interior relies heavily on large-scale water withdrawal for irrigation. Water from small seasonal creeks and similar sources of clear water are extracted for agricultural purposes while juvenile chinook are temporarily rearing in them (e.g. Hawk's Creek, Scriverner et al. 1993). In some areas irrigation water is withdrawn through pumping directly from the mainstream (M. Crowe, personal communication). In this case the pump intakes are often placed in the deeper pools where salmonids congregate. If intakes are not properly screened juvenile fish are vaccumed up.

Groundwater wells may also be used to provide irrigation water. The importance of groundwater in maintaining base flows and in moderating stream temperatures must be considered (Power et al. 1999, Walthers and Nener 1997). Consideration should be given to identifying, mapping, protecting, and maintaining the groundwater resources in order to protect and maintain sensitive fish habitats (Blackport et al. 1995; Walthers and Nener 1997). Agricultural development can have a major impact on coho production through the loss of groundwater influenced sloughs and side channels (Sheng 1993). These sites are often filled or blocked off.

The improper construction of flood irrigation ditches on larger streams poses a potential stranding problem to migrating juvenile salmon. In the Nicola Valley, Fleming et al. (1987) documented 4,100 chinook ($0.12/m^2$) and 3,700 rainbow trout ($0.18/m^2$), stranded in irrigation ditches and assumed lost when dewatered in October. In the Thompson Valley ditches have been noted to strand juvenile salmon and unspawned adult salmon (M. Crowe, personal communication). In the Chilcotin River during recent ranching reviews, juvenile chinook were found to be heavily utilizing flood irrigation ditches during spring high flow (D. Desrochers, personal communication). Fish residing in the irrigation ditches are lost when water levels fall although more permanent groundwater fed ditches may be used as rearing habitats for juvenile salmon (Fleming et al. 1987).

In the upper Buckley Valley, high densities of juvenile coho are found in the ditches designed to drain natural wetlands (T. Pendray, personal communication). It is possible that temporary fish use of some shallow wetlands may be limited due to the dispersal of floodwaters over a wide shallow area. Constructed ditches may concentrate the limited waters and make it available to fish. It is also possible that the constructed ditches simply concentrate the fish and eliminate the previously flooded lands from fish use. The draining of interior wetlands also ignores the hydrological importance of these areas for the entire watershed. The relationship between fish use of flooded interior meadows before and after drainage has never been examined.

Summary of Impacts of Urban Development and Agriculture

- The removal of the river channel from its floodplain through hydromodification has isolated or eliminated > 70% of the Fraser Valley wetlands. It is hard to quantify fish habitat values associated with wetland loss.
- Where human values are high, few viable options remain to maintain or regain lost fish habitats.
- Flood control measures have the potential to alter access to floodplain sites in autumn.
- Unseasonable water releases can send false cues to fish and promote stranding, a reduction in peak flows can reduce channel avulsion and succession of off-channel habitats.
- Transportation corridors tend to fix the river channel into a specific location
- Improperly installed culverts can eliminate juvenile fish access to off-channel habitats.
- Urban development has the greatest impact on the hydrological regime (increases in storm magnitude, reduction in time to peak).
- Water quality is degraded by urban stormwater, landfills, woodwaste piles, municipal sewage, and septic fields. Our ability to deal with urban development and stormwater is questionable.
- Agricultural runoff includes inputs of manure, fertilizers, sediments, and pesticides and their residues. Flooding and high rainfall can aggravate water quality problems
- Considerable nitrate-N loading occurs in agricultural areas. However N levels can be higher during summer low flows due to contaminated groundwater than in winter when rainwater dilutes the concentrations of nutrients.
- The wood industry is the largest single user group of pesticides (86% by weight) followed by the agricultural industry.
- Wetlands and natural channels function differently from ditches and drained lands. Dyking and ditching has been to the detriment of fish habitats.

References

Abbe, T., A. Brooks, D. Montgomery, and C. Gippel. 2000. The geomorphic role of wood debris in the rehabilitation and management of fluvial environments. In International Conference on Wood in World Rivers. Oct 23-27, 2000. Oregon State University, Corvallis, Oregon. Abstracts 139p.

Anderson, E.P., I.K. Birtwell, S.C. Byers, A.V. Hincks and G.W. O'Connell. 1981. Environmental effects of harbour construction activities at Steveston, British Columbia. Part 1. Main Report. Can. Tec. Rep. Fish. Aquat. Sci. 1070: 160p.

Anderson, J.L., and J.E. Wilen. 1985. Estimating the population dynamics of coho salmon (*Oncorhynchus kisutch*) using pooled time-series and cross-sectional data. Can. J. Fish. Aquat. Sci. 42:459-467.

Anderson H. and R. Hobba. 1959. Forests and floods in the Northwestern United States. International Association of Scientific Hydrology. Publication 48, pp. 30-39.

Anderson, L. and M. Bryant. 1980. Fish passage at road crossing: an annotated bibliography. General technical report PNW:117. 10p.

Andrus, C.W., B.A. Long and H.A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. Can. J. Fish. Aquat. Sci. 45(12):2080-2086.

Andrus, C.W., D.H. Landers, M.L. Erway, D. Sharps and S.P.Cline. 1997. Ecological functions of off-channel habitat, Willamette River, Oregon. Final Research Plan. Report: EPA/600/R-98/004. Abstract Only.

Armstrong, R.H. 1984. Migration of anadromous Dolly Varden charr in southeastern Alaska – a manager's nightmare. In L. Johnson and B. Burn (*eds*) Proceedings of the International Symposium on Artic Charr, 1984. pp. 559-570.

Atagi, D.Y. 1994. Estuarine use by juvenile coho salmon (*Oncorhynchus kisutch*): is it a viable life history strategy? MSc. Department of Zoology, University of British Columbia, Vancouver, B.C., Canada. 108p.

Atwater, J.W. 1980. Fraser River Estuary Study. Water Quality. Impact of Landfills. Government of Canada, Environmental Protection Service. 285p.

B.C. Coastal Fisheries/Forestry Guidelines Technical Committee. 1987. British Columbia coastal Fisheries/ Forestry Guidelines, Unpublished series of Appendix by Research Branch, Ministry of Forests, Victoria, B.C. 113p.

B.C. Coastal Fisheries/Forestry Guidelines Technical Committee. 1992. British Columbia coastal Fisheries/ Forestry Guidelines 3rd Draft, Published by Research Branch, Ministry of Forests, Victoria, B.C. 102p.

B.C. Ministry of Forests. 2002. Fish-stream crossing guidebook. For. Prac. Br., Min. For., Victoria, B.C. Forest Practices Code of British Columbia guidebook. 68p.

Bams, R.A. 1990. Outplanting normal and sterilized hatchery coho fall fingerlings into two small British Columbia lakes: An evaluation. Can. Tech. Rep. Fish. Aquat. Sci. 1765:31p.

Bates, D. 2002. Evaluation of the smolt production from constructed off-channel and mainstem rearing habitats in the Vancouver River watershed, Jervis Inlet, B.C. Report prepared for Habitat Enhancement Branch, Dept. Fisheries and Oceans, Nanaimo, B.C. 12p.

Bauer, W. 1977. Vancouver Island south-east coast shore-resource inventory and analyses. Unpublished Manuscript 100p + Maps. (Pacific Biological Stn. Library, Nanaimo, B.C.).

Beacham, T.D. and P.A.F, Starr. 1982. Population biology of chum salmon, *Oncorhynchus keta*, from the Fraser River, British Columbia. Fish. Bull. 80(4):813-825.

Beaudry, P. and D.L. Golding. 1983. Snowmelt during rain-on-snow in coastal British Columbia, Proceeding of the 51st Annual Western Snow Conference, Vancouver, Washington. Pp.55-66.

Becher, K.D., D.J. Schnoebelen and K.K.B. Akers. 2000. Nutrients discharged to the Mississippi River from eastern Iowa watersheds, 1996-1997. J. Am. Water Resour. Assoc. 36(1):161-174.

Beckman, B.R., D.A. Larsen, C. Sharpe, B. Lee-Pawlak, C.B. Schreck, and W.W. Dickhoff. 2000. Physiological status of naturally reared juvenile spring chinook salmon in the Yakima River: Seasonal dynamics and changes associated with smolting. Trans. Am. Fish. Soc. 129:727-753.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. N. Am. J. Fish. Manage. 14:797-811.

Beechie, T.J. and T.H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in Northwestern Washington streams. Trans. American Fish. Soc. 126:217-229.

Beesion, C.E. and P.F. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Water Resour. Bull. 31:983-990.

Belknap, W. and R.J Naiman. 1994. Locating, detecting, and mapping wall-base channels in western Washington. Center for Streamside Studies, AR-10, University of Washington, Seattle. Report to the Washington State Department of Natural Resources. 65p.

Bell, E., W. Duffy, and T.D. Roelofs. 2001. Fidelity and survival of juvenile coho salmon in response to a flood. Trans. Amer. Fish. Soc. 130:450-458.

Belsky, A.J. and A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. J. Soil Water Conserv. 54(1):419-431.

Beltaos, S. and P.F. Doyle. 1996. Ice jam mitigation using setback dykes: Coldwater River at Merritt, B.C. J. Cold Regions Eng. 10(4):190-206. (Abstract only)

Ben-David, M, T.A. Hanley, and D.M. Schell. 1998. Fertilization of terrestrial vegetation by spawning Pacific sallmon: The role of flooding and predator activity. Oikos 83(1)47-55.

Bengtson, G.W. 1979. Forest fertilization in the United States: progress and outlook. J. For. 77(4):222-229.

Benke, A.C. 2001. Importance of flood regime to invertebrate habitat in an unregulated river-floodplain ecosystem. Journal of the North American Benthological Society, Vol. 20, No. 2. Pp.225-240.

Bergamaschi, B.A., K.M. Kuivila, and M.S. Fram. 2001. Pesticides associated with suspended sediments entering San Francisco Bay following the first major storm of water year 1996. 2001. Estuaries 24(3)368-380.

Berka, C. H. Schreier, K. Hall. 2001. Linking water quality with agricultural intensification in a rural watershed. Water, Air, Soil Pollut. 127:389-401.

Bernard, D.R. K.R. Hepler, J.D. Jones, M.E. Whalen, and D.N. McBride. 1995. Some tests of the "migration hypothesis" for anadromous Dolly Varden (southern form). Trans. Am. Fish. Soc. 124(3):297-307.

Bilby, R.E. 1984. Removal of woody debris may affect stream stability. J. For. 82:609-613.
Bilby, R.E. and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Trans. Am. Fish. Soc. 118:368-378.

Bilby, R.E. and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Trans. Am. Fish. Soc. 118:368-378.

Bilby, RE. and P.A. Bisson. 1987. Emigration and production of hatchery coho salmon (*Oncorhynchus kisutch*) stocked in streams draining an old-growth and clear-cut watershed. Can. J. Fish. Aquat. Sci. 44:1397-1407.

Bilby, RE. and P.A. Bisson. 1992. Allochthonous versus autochtonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. Can. J. Fish. Aquat. Sci. 49(3):540-551.

Birtwell, I.K., C.D. Levings, J.S. MacDonald, and I.H. Rogers. 1988. A review of fish habitat issues in the Fraser River system. Water pollution research journal of Canada. 23(1):1-30.

Birtwell, I.K., M. Wood, D.K. Gordon. 1984. Fish diets and benthic invertebrates in the estuary of the Somass River, Port Alberni, British Columbia. Can. MS. Rep. Fish. Aquat. Sci. 1799. 49p.

Birtwell, I.K., M.D. Nassichuk and H. Beune. 1987a. Underyearling sockeye salmon (*Oncorhynchus nerka*) in the estuary of the Fraser River, pages 36-43. *In* H.D. Smith, L. Margolis, and C.Wood (ed.). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96:486p

Birtwell, I.K., M.D. Nassichuk, H. Beune and M. Gang. 1987b. Deas Slough, Fraser River Estuary, British Columbia; general description and some aquatic characteristics. Can. MS. Fish. Aquat. Sci. 1926:45p.

Birtwell, I.K., R.P.Fink, J.S. Korstrom, B.J. Fink, J.A. Tanaka and D.J. Tiessen.. 1998. Vertical distribution of juvenile chum salmon (Oncorhynchus keta) in relation to a thermal discharge into Port Moody, Burrard Inlet, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2235:111p.

Bisson, P.A., Sullivan, K., and Nielsen, J.L. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Trans. Am. Fish. Soc. 117:262-273.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Trans. Amer. Fish. Soc. 100(3):423-438.

Blachut, S.P. 1988. The winter hydrological regime of the Nechako River, British Columbia. Can. MS. Rep. Fish. Aquat. Sci. 1964:145p.

Blackport, R., R. MacGregor and J. Imhof. 1995. An approach to the management of goundwater resources to protect and enhance fish habitat. Can. MS. Rep. Fish. Aquat. Sci. 2284:85p.

Blackwell, C.N., C.R. Picard, and M. Foy. 1999. Smolt productivity of off-channel habitats in the Chilliwack River watershed, B.C. Ministry of Environment, Lands and Parks, and B.C. Ministry of Forests. Watershed Restoration Project Report No. 14: 46 p.

Bonnell, R.G. 1991. Construction, operation, and evaluation of groundwater-fed side channels for chum salmon in British Columbia. Am. Fish. Soc. Symp. 10:109-124.

Booth, D.B. 1991. Urbanization and the natural drainage system – impacts, solutions, and prognoses. The Northwest Env. J. 7(1):93-118.

Booth ,D.B., and C.R. Jackson. 1997. Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation. Journal of American Water Resources Association 33:1077-1090.

Bosch J.M. and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol., 55:3-23.

Bothwell, M.L., Sherbot, D.M.J. and C.M. Pollock. 1994. Ecosystem response to solar ultraviolet-B radiation: Influences of trophic-level interactions. Science 265:97-100.

Boulton, A.J., C.G. Peterson, N.B. Grimm, and S.G. Fisher. 1992. Stability of an aquatic macroinvertebrate community in a multiyear hydrologic disturbance regime. Ecology 73:2192-2207.

Bozek, M.A. and F.J. Rahel. 1991. Assessing habitat requirements of young Colorado River cutthroat trout by use of macrohabitat and microhabitat analyses. Trans. Am. Fish. Soc. 120():571-581.

Bradford, M.J. 1997. An experimental study of stranding of juvenile salmonids on gravel bars and in sidechannels during rapid flow decreases. Regul. Rivers: Res. Mgmt. 13:395-401.

Bradford, M.J. 1999. Temporal and spatial trends in the abundance of coho salmon smolts from western North America. Trans. Amer. Fish. Soc. 128:840-846.

Bradford, M.J., J.A. Grout, and S. Moodie. 2001. Ecology of juvenile chinook salmon in a small non-natal stream of the Yukon River drainage and the role of ice conditions on their distribution and survival. Can. J. Zool. 79(11):2043-2054.

Bradford, M.J. and J.R. Irvine. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Can. J. Fish. Aquat. Sci. 57:13-16.

Bradford, M.J., G.C. Taylor and J.A. Allan. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Trans. American Fish. Soc. 126:49-64.

Bradford, M.J., G.C. Taylor, J.A. Allan, and P.S. Higgins. 1995. An experimental study of stranding of juvenile coho salmon and rainbow trout during rapid flow decreases in winter conditions. North Am. J. Fish. Manage. 15:473-479.

Bradford, M.J. and P.S. Higgins. 2001. Habitat-, season-, and size-specific variation in diel activity patterns of juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 58(2):365-374.

Bratty, J.M. 1999. The winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) in interior British Columbia streams. MSc. Department of Resource management and Environmental Studies. University of British Columbia, Vancouver, B.C., Canada. 131p.

Bravender, B.A. C. Annand, A. Hillaby, and J. Naylor. 1997. Fish species, juvenile chinook diets and epibenthos in the Englishman River estuary, 1993. Can. Data Rep. Fish. Aquat. Sci. 1021. 41p.

Bravender, B.A., L.A. MacDougall, L.R. Russell, C. Beggs, and D. Miller. 2002. Juvenile salmon survey, 1998, Courtenay River estuary, Courtenay, B.C. Can. Tech. Rep. Fish. Aquat. Sci. 2395:63p.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Board Can. 9(6):265-323.

Brown . G.W. 1969. Predicting temperatures of small streams. Water Resour. Res. 5(1):68-75..

Brown, G.W. 1970. Predicting the effect of clearcutting on stream temperature. J. Soil and Water Conservation. 25:11-13.

Brown, G.W. 1980. Forestry and Water Quality. O.S.U. Book Stores, Inc., Corvallis, Oregon. 124p.

Brown, G.W. and J.T. Krygier. 1979. Effects of clearcutting on stream temperature. Water Resour. Res. 6(4):1133-1199.

Brown, R.S. G. Power, S. Beltaos, and T.A. Beddow. 2000. Effects of hanging ice dams on winter movements and swimming sctivity of fish. J. Fish. Biol. 57(5):1150-1159.

Brown, R.S., S.S. Stanislawski, and W.C. Mackay 1994. Effects of frazil ice on fish. *In* T.D. Prowse, (*ed*) pages 261-278, Proceedings of the Workshop on Environmental Aspects of River Ice, NHRI Symposium Series No.12.

Brown, R.S. and W.C. Mackay. 1995. Fall and winter movements of and habitat use by cutthroat trout in the Ram River, Alberta. Trans. American Fish. Soc. 124:873-885.

Brown, T.J., T.R. Whitehouse and C.D. Levings. 1989. Beach seine data from the Fraser River at the north arm, main arm, and Agassiz during 1987-88. Can. Data Rep. Fish. Aquat. Sci. 737:134p.

Brown, T.G. 1985. The role of abandoned stream channels as over-wintering habitat for juvenile salmonids. MSc. Faculty of Forestry, University of British Columbia, Vancouver, B.C., Canada. 134p.

Brown, T.G. 1987. Characterization of salmonid over-wintering habitat within seasonally flooded land on the Carnation Creek flood-plain. B.C. Min. For. Land Manage. Rep. No. 44: 42p.

Brown, T.G. and G.F. Hartman. 1988. The contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Trans. Am. Fish. Soc. 117(6):546-551

Brown, T.G. and T.E. McMahon. 1988. Winter ecology of juvenile coho salmon in Carnation Creek: Summary of findings and management implications. Pages 108-117. In: T.W. Chamberlin

(Ed.), Proceedings of the workshop: Applying 15 years of Carnation Creek results. Pacific Biological Station, Nanaimo, B.C. 239p.

Brown, T.G. and P. Winchell. 2002. Use of Shuswap Lake foreshore by juvenile salmonids. Paper given at Institute of Ocean Science, Victoria, B.C. at MEHSD all staff meeting on Nov. 27/2002. 11p.

Brown, T.G., B.C. Andersen, J.C. Scrivener, and I.V. Williams. 1989. Fish Survey of S.E. Clayquot Sound Streams, Vancouver Island. Can. Man. Rep. Fish. and Aquat. Sci. No. 2021. 71p.

Brown, T.G., E.White, D. Kelly, L. Rzen, and J. Rutten. 1994. Availability of juvenile chinook salmon to predators along the margins of the Nechako and Stuart Rivers, B.C. Can Ms. Rep. Fish. Aquat. Sci. 2245: 34p.

Brown, T.G., L. Barton, and G. Langford. 1996. The use of a geographic information system to evaluate terrain resource information management (TRIM) maps and to measure land use patterns for Black Creek, Vancouver Island. Can. Manuscr. Rep. Fish. Aquat. Sci. 2395:34p.

Brown, T.G., L. Barton, and G. Langford. 1999. Coho salmon habitat within Black Creek, Vancouver Island. 1999. Can. Tech. Rep. Fish. Aquat. Sci. 2294::75p.

Brownlee, M.J. and D.C. Morrison. 1983. A preliminary fisheries examination of the content, application and administration of the stream protection clauses ("p" clauses) on Vancouver Island. Report Published by Habitat Management Division, Department of Fisheries and Oceans. Vancouver. 28p.

Brownlee, M.J., B.G. Shepheard, and D.R. Bustard. 1988. Some effects of forest harvesting on water quality in the Slim Creek watershed in the central interior of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1613:41p.

Bryant, L.D. 1982. Response of livestock to riparian zone exclusion. J. Range Manage. 35:780-785.

Bryant, M.D. 1983. The role and managemen;t of woody debris in west coast salmonid nursery streams. North American Journal of Fisheries Management 3:322-330.

Bryant, M.D. 1988. Gravel pit ponds as habitat enhancement for juvenile coho salmon. Gen. Tech. Rep. USDA For. Serv. Pac. NW. Res. Stn., 17p.

Bryant, M.D., B.E. Wright, and B.J. Davies. 1992. Application of a hierarchical habitat unit classification system: steam habitat and salmonid distribution in Ward Creek, Southeast Alaska. 1992. US. Dept. Agric. Forest Service, PNW Research Stn. Reasearch Note, PNW-RN-508. 18p.

Bryant, M.D., B.J. Frenette and K.T. Coghill. 1996. Use of littoral zone by introduced anadromous salmonids and resident trout, Margaret Lake, southeast Alaska. Alaska Fish. Res. Bull. 3(2);112-122.

Buijse, A.D. and F.T. Vriese. 1996. Assessing potential fish stocks in new nature developments in floodplains of large rivers in the Netherlands. Pages 339-343, in The Ecology of Large Rivers. Arch. Hydrobiol. (Suppl.) Large Rivers 113(1-4).

Buhl, K.J. and S.J. Hamilton. 1998. Acute toxicity of fire-retardant and foam-suppressant chemicals to early life stages of chinook salmon (Oncorhynchus tshawytscha). Environ. Toxicol. Chem. 17(8):1589-1599.

Buhl, K.J. and S.J. Hamilton. 2000. Acute toxicity of fire-control chemicals, nitrogenous chemicals, and surfactants to rainbow trout. Trans. Am. Fish. Soc. 129(2):408-418.

Burns, D.C. 1991. Cumulative effects of small modifications to habitat. AFS Position Statement. Fisheries 16(1):12-17.

Burns, T., EA. Harding, and B.D. Tutty. 1987. Cowichan River assessment (1987): The influence of river discharge on sidechannel fish habitats. Can. MS Rep. Aquat. Sci. No. 1999:24p.

Burt, D.W. and J.H. Mundie. 1986. Case histories of regulated stream flow and its effects on salmonid populations. Can. Tech, Rep, Fish. Aquat. Sci. 1477::98p.

Bustard, D. R. 1986. Some differences between coastal and interior stream ecosystems and the implication to juvenile fish production. Pages 117-126, *in* J.H. Patterson (ed.), Proceedings of the Workshop on Habitat Improvements, Whistler, B.C., Can. Tech. Rep. Fish. and Aquatic Sci. No. 1483.

Bustard, D.R., and D.W. Narver. 1975a. Aspects of the winter ecology of juvenile coho salmon (*Oncorhyncus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal Fisheries Research Board of Canada 32:667-680.

Bustard, D.R. and D.W. Narver. 1975b. Preferences of juvenile coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) relative to simulated alteration of winter habitat. J. Fish. Res. Bd. Can. 32:681-687.

Bustard, D.R. 1983. Quenn Charlotte Islands stream rehabilitation studies – a review of potential techniques. Fish/Forestry Interaction Program Working Paper 8/83, B.C. Ministry of Forests. 31p.

Buttle, J.M. and R.A. Metcalfe. 2000. Boreal forest disturbance and streamflow response, northeastern Ontario. Can. J. Fish. Aquat. Sci. 57(Suppl. 2): 5-18.

Cada, G.F. M.D. Deacon, S.V. Mitz, and M.S. Bevelhimer. 1997. Effects of water velocity on the survival of downstream-migrating juvenile salmon and steelhead: A review with emphasis on the Columbia River Basin. Review in Fisheries Science 5(2)131-183.

Caffrey, J.M. 1996. Glyphosate in fisheries management. Hydrobiologia. 340:259-263.

Cameron, E.M., G.E.M. Hall, J. Veizer, and H.R. Krouse. 1995. Isotopic and elemental hydrogeochemistry of a major river system: Fraser River, British Columbia, Canada. Chemical Geology, Vol. 122, No. 1, pp. 149-169.

Canada Soil Survey Committee. 1978. The Canadian system of soil classification. Can. Dep. Agric. Publ. 1646. Supply and Services Canada, Ottawa, Ont. 164p.

Carter. C.E. and R.B. Wood. 1995. The winter macrobenthos of the Clough River system, Northern Ireland. J. Feshwat. Ecol. 10(4):361-366.

Carver, M. 2001. Draft Report. Riparian forest management for protection of aquatic values: Literature review and synthesis. Report prepared for Forest Stewardship Council by Carver Consulting, 310 Houston St. Nelson, B.C. 48p

Castelle, A.J., C. Conolly, M. Emers, E.D. Metz, S. Meyer, M. Witter, S. Mauermann, T. Erickson, S.S. Cooke. 1992. Wetland Buffers: Use and Effectiveness. Adolfson Associates, Inc., Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, No. 92-10. 54p.

Castelle, A.J., A.W. Johnston, and C. Conolly. 1994. Wetland and stream buffer size requirements – a review. J. Environ. Qual. 23:878-882 (1994).

Cavanagh, N. and T.L. McDaniels. 1997. Perceptions of ecological risks associated with eutrophication sources in the lower Fraser River basin, British Columbia. Can. Water Resourc. J. 22(4):433-444.

Cederholm, C.J. and L.M. Reid. 1987. Impact of forest management on coho salmon (*Oncorhynchus kisutch*) population of the Clearwater River, Washington: a project summary. Pages 373-398. *In* E. O. Salo and T.W. Cundy [ed.]. Streamside management: forestry and fishery interactions. University of Washington, Seattle.

Cederholm C.J. and N.P. Peterson. 1989. A summary comparison of two types of winter habitat enhancement for juvenile coho salmon in the Clearwater River, Washington. *In* B.G. Shepherd (ed), Proceedings of the 1988 Northeast Pacific chinook and coho salmon workshop. Bellingham Washington. Pages 227-239.

Cederholm, C. J. and W.J. Scarlett. 1982.. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Pages 98-110 *in* E.L. Brannon and E. O. Salo, editors. Proceedings of the salmon and trout migratory behaviour symposium. University of Washington, School of Fisheries, Seattle.

Cederholm, C.J. and W.J Scarlett. 1991. The beaded channel: a low-cost technique for enhancing winter habitat of coho salmon. Amer. Fish. Soc. Symposium 10:104-108.

Cederholm, C.J., D.B. Houston, D.L. Cole, and W.J. Scarlett. 1989. Fate of coho salmon (*Oncorhynchus kisutch*) carcasses in spawning streams. Can. J. Fish. Aquat. Sci. 46:1347-1355.

Cederholm, C.J. D.H. Johnson, R.E. Bilby, L.G. Dominguez, A. M. Garrett, W. H. Graeber, E.L. Greda, M.D. Kunze, B.G. Marcot, J.F. Palmisano, R. W. Plotnikoff, W.G. Rearcy, C.A. Simenstad, and P.C. Trotter. 2000. Pacific Salmon and Wildlife – Ecological Contexts, Relationships, and Implications for Management. Special Edition Technical Report, Prepared for D.H. Johnson and T.A. O'Neil (Managing directors), Wildlife-Habitat Relationships in Oregon and Washington. Washington Department of Fish and Wildlife, Olympia, Washington.

Cederholm, C.J., M.D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24(10):6-15.

Cederholm, C.J., R.E. Bilby, P.A. Bisson, T.W. Bumstead, B.R. Fransedn, W.J. Scarlett, and J.W. Ward. (1997). Response of juvenile salmon and steelhead to placement of large woody debris in a coastal Washington stream. N. Am. J. Fish. Manage. 17(4):947-963.

Cederholm, C.J., W.J. Scarlett, and N.P. Peterson. 1988. Low-cost enhancement technique for winter habitat of juvenile coho salmon. North American Journal of Fisheries Management 8:438-441.

Chamberlin, T.W. 1982. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America. 3. Timber Harvest. USDA. Forest Service. PNW-136.

Chapman, D.W. and E. Knudsen. 1980. Channelization and livestock impacts on salmonid habitat and biomass in western Washington. Trans. Amer. Fish. Soc. 109:357-363.

Chapman, D.W. and T. C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding. Pages 153-176 *in* T.G. Northcote (ed.). Symposium on salmon and trout streams. H.R. Macmillan lectures on fisheries. University of British Columbia, Vancouver, B.C. February 1968.

Chatwin, S., P. Tshaplinski, G. McKinnon, N. Winfield, H. Goldberg, R. Schere. 2001. Assessment of the condition of small fish-bearing streams in the central interior plateau of British Columbia in response to riparian practices implemented under the Forest Practices Code. Res. Br., B.C. Min. For., Victoria, B.C. Work. Pap. 61/2001.

Cheng, J. D. 1989. Streamflow changes after clear-cut logging of a pine beetle infested watershed in southern British Columbia, Canada. Water Resour. Res. 25:449-456.

Cheng, J.D., T.A. Black, J. de Vries, R.P. Willington, and B.C. Goodell. 1975. The evaluation of initial changes in peak streamflow following logging of a watershed on the west coast of Canada. Ass. Sci. Hydrol. Publ., 117:475-486.

Chilliwack Museum. 2002. The Land: Draining the Lake. Chilliwack Museum and Archives. http://chilliwack.museum.bc.ca/history/theland/drain.htm

Chisholm, I.M., W.A. Hubert and T.A. Wesche. 1987. Winter stream conditions and use of habitat by brook trout in high-elevation Wyoming steams. Trans. Am. Fish. Soc. 116(2):176-184.

Choate, J.S. 1972. Effects of stream channeling on wetlands in a Minnesota watershed. Journal of Wildlife Management 36(3):940-944.

Choromanski, E.M., J.S. Macdonald, and J.C. Scrivener. 1994. Invertebrate production in the Takla Tributaries. Pages 15-18, *In* J.S. Macdonald (ed) Proceedings of the Takla Fishery/Forestry Workshop: a two year review. Can Tech Rep. Fish. Aquat. Sci. 2007:104p.

Christner J. and R.D. Harr. 1982. Peak streamflows from the transient snow zone. Western Cascades, Oregon. Eastern/Western Snow Conference (50th Annual Meeting) Reno, Nevada. pp27-38.

Church, M. 1992. Channel morphology and typology. *Pages* 126-143 *in* P. Calow and G.W. Petts (eds.) The Rivers Handbook, Vol 1. Blackwell, Oxford.

Church, M. and B. Eaton. 2001. Hydrological effects of forest harvest in the Pacific Northwest. Technical Report to Central Coast Land Resource Management Planning Table. 76p.

Claret, C. A.J. Boulton, M-J. Dole-Oliver and P. Marmonier. 2001. Functional process versus state variables; interstitial organic matter pathways in floodplain habitats. Can. J. Fish Aquat. Sci. 58(8):1594-1602.

Collen, P. and R.J. Gibson. 2000. The general ecology of beavers (*Castor* spp.), as related to their influence on stream ecosystems and riparian habitats, and the subsequent effects on fish – a review. Rev. Fish Biol. Fish. 10(4):439-461.

Conover, D.O. 1992. Seasonality and the scheduling of life history at different latitudes. J. Fish. Biol. 41(sup B):161-178.

Contor, C.R. and J.S. Griffith. 1995. Nocturnal emergence of juvenile rainbow torut from winter concealment relative to light intensity. Hydrobiologia 299(3):179-`83.

Coote, D.R. and L.J. Gregorich. 2002. The Health of Our Water. Agriculture and Agri-Food Canada, Research Branch.

Cordes, L.D. 1972. An ecological study of the Sitka spruce forest on the west coast of Vancouver Island. Ph.D. Thesis. University of British Columbia Dept of Botany. Vancouver, B.C. Canada. 452p.

Cowardin, L.M. V.Carter, F.C. Golet and E.T. LsRoe. 1979. Classification of wetlands and depwater habitats of the United States. United States, Fish and Wildlife Service 35p.

Cowx, I.G., G.A. Wheatley and A.S. Mosley. 1986. Long-term effects of land drainage works on fish stocks in the upper reaches of a lowland river. J. Environ. Manage. 22(2);147-156.

Crone, R.A. and C.E. Bond. 1976. Life history of coho salmon, *Oncorhynchus kisutch*, in Sashin Creek, southeast Alaska. U.S. Fish. Bull. 74:897-923.

Crowther, R. S. 1997. Summary Technical Report. Richmond Landfill 1996 Pollution Prevention Plan. Environment Canada. Environmental Protection. DOE-FRAP 1997-07.

Culp, J.M.and R.W. Davies. 1983. An assessment of the effects of streambank clear-cutting on macroinvertebrate communities in a managed watershed. Can. Tech. Rep. Fish. Aquat. Sci. 1208:116p.

Culp, J.M., F.J. Wrona, and R.W. Davies. 1986. Response of stream benthos and drift to fine sediment deposition versus transport. Can. J. Zool. 64:1345-1351.

Cunjak, R.A. 1988a. Behaviour and microhabitat of young Atlantic salmon (*Salmo salar*) during winter. Can. J. Fish. Aquat. Sci. 45:2156-2160.

Cunjak, R.A. 1988b. The physiological consequences of overwintering: the cost of acclimatization? Can. J. Fish. Aquat. Sci. 45:443-452.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Can. J. Fish. Aquat. Sci. 53:267-282.

Cunjak, R.A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout and brown trout. Can. J. Fish. Aquat. Sci. 43:1970-1981.

Cunjak, R.A. and G. Power. 1987a. Cover use by stream resident trout in winter: a field experiment. N. Amer. J. Fish. Manage. 7:539-544.

Cunjak, R.A. and G. Power. 1987b. The feeding and energetics of stream-resident trout in winter. J. Fish Biol. 31:493-511.

Cunjak, R.A., T.D. Prowse and D.L. Parrish. 1998. Atlantic salmon (*Salmo salar*) in winter. "the season of parr discontent"? Can. J. Fish. and Aquatic Sci. 55(sup1):161-180.

Dane, B.G. 1978. Culvert guidelines: recommendations for the design and installation of culverts in British Columbia to avoid conflict with anadromous fish. Fish. Marine Ser. Tech. Rep. No. 811. 57p.

De Leeuw, A.D. 1982. Effects of two winter flood events on juvenile salmonids and associated rearing habitat in the Salmon River (Langley). MS. Report, Fish Habitat Improvement Section, Fish and Wildlife Branch, Ministry of Environment, Victoria, B.C. 32p+Appendix.

Decker, A. S. 1999. Effects of primary production and other factors on the size and abundance of juvenile coho salmon in artificial off-channel habitat. MSc. Faculty of Forestry, University of British Columbia, Vancouver, B.C., Canada. 146p.

Decker A.S. and M.J. Lightly. (In Press) The contribution of constructed side-channels to coho salmon smolt production in the Oyster River. Can. Tech. Rep.. Fish. and Aquat. Sci. 32p.

DeCicco, A.L. and J.B. Reynolds. 1997. Movements of postsmolt anadromous Dolly Varden in northwestern Alaska. Symp. Am. Fish. Soc. 19:175-183.

Delaney, P.W., A.L. Kohl, W.R. Olmsted and B.C. Pearce. 1982. Studies of chinook salmon (*Oncorhynchus tshawytscha*) in the Chilcotin River watershed 1975-1980. Can. MS Rep. Fish. Aquat. Sci. 1974:162p.

Dettmers, J.M., D.H. Wahl, D.A. Soluk, S. Gutreuter. 2001. Life in the fast lane: fish and foodweb structure in the main channel of large rivers. Journal of the North American Benthological Society. Vol. 20, No 2. pp. 255-265.

Dewberry, C., P. Burns and L. Hood. 1998. After the flood. The effects of the storms of 1996 on a creek restoration project in Oregon. Restoration and Management Notes 16(2):174-182. (Abstract only).

Dill, L.M. 1983. Adaptive flexibility in the foraging behavior of fishes. Can. J. Fish. Aquat. Sci. 40(4):398-408.

Dolloff. C.A. 1987. Seasonal population characteristics and habitat use by juvenile coho salmon in a small southeast Alaska stream. Trans. Amer. Fish. Soc. 116:829-838.

Dolloff, C.A. and G.H. Reeves. 1990. Microhabitat partitioning among stream-dwelling juvenile coho salmon, *Oncorhynchus kisutch*, and Dolly Varden, *Salvelinus malma*. Can. J. Fish. Aquat. Sci. 47(12)2297-2306.

Dorava, J.M. and A.M. Milner. 2000. Role of lake regulation on glacier-fed rivers in enhancing salmon productivity: the Cook Inlet watershed, south-central Alaska, USA.

Dosskey, M.G. 2001. Toward quantifying water pollution abatement in response to installing buffers on crop land. Environ. Manage. 28(5):577-598.

Doyle, P.F., G.T. Kosakoski and R.W. Costerton. 1994. Negative effects of freeze-up and breakup on fish in the Nicola River. *In* T.D. Prowse, (*ed*) pages 299-314, Proceedings of the Workshop on Environmental Aspects of River Ice, NHRI Symposium Series No.12.

Drinnan, R.W., B. Emmett, B. Humphrey. B. Austin, and D. J. Hull. 1995. Saanich Inlet Study. Water use inventory and water quality assessment. Water Quality Branch, Environmental Protection Department, B.C. Ministry of Environment, Lands and Parks.

Edmundson, E.H., F.H. Everest, and D.W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. J. Fish. Res. Bd. Can. 25:1453-1464.

Eiler, J.H. B.D. Nelson, and R.R. Bradshaw. 1992. Riverine spawning by sockeye salmon in the Taku River, Alaska and British Columbia. Trans. Am. Fish. Soc. 121(6):701-708.

Elliott, S.T. 1992. A rough trap for caching coho salmon smolts emigrating from beaver ponds. N. Am. J. Fish. Manage. 12(4):837-840.

Elliot, S.T. and R.D Reed. 1975. Ecology of rearing fish. Alaska Dep. Fish Game, Div. Sport Fish, Ann. Rep #15. Abstract Only.

Elwood, J.W. and T.F. Waters. 1969. Effects of floods on food consumption and production of a stream brook trout population. Trans. Am. Fish. Soc. 98:253-262.

Emmett, B., L. Convey and K. English. 1992. An early winter survey of juvenile chinook in the Nechako River. Draft Report, by Archipelago Marine Research and LGL Ltd for Salmon Habitat Section, Department of Fisheries and Oceans, PBS, Nanaimo B.C. 36p.

ENKON Environmental Limited. 2001. Survey of pesticide use in British Columbia: 1999. Environment Canada. North Vancouver, B.C. 48p + Appendix.

Everest, F.H. and D.W. Chapman, 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout. J. Fish. Res. Board Can. 29:91-100.

Everest, F.H. and R.D. Harr. 1982. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America. 6. Silvicultural Treatments USDA. Forest Service. PNW-134.

Everest, F.H., and W.R. Meehan. 1981. Forest management and anadromous fish habitat productivity. Transactions of the 46th North American Wildlife and Natural Resources Conference. Published by the Wildlife Management Institute, Washington D.C. pp. 521-530.

Fausch, K.D. and T.G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Can. J. Aquat. Sci. 49:682-693.

Fedorenko, A.Y. and B.C. Pearce. 1982. Trapping and coded wire tagging of wild juvenile chinook salmon in the South Thompson/Shuswap River System 1976, 1979, 1980. Can. MS. Rep. Fish. Aquat. Sci. 1677. 63p.

Fedorenko, A.Y. and R.J. Cook. 1982. Trapping and coded wire tagging of wild coho juveniles in the Vedder-Chilliwack River, 1976 to 1979. Can. MS. Rep. Fish. Aquat. Sci. 1678. 79p.

Ferguson, K.D. and K.J. Hall. 1979. Fraser River Estuary Study. Water Quality. Stormwater Discharges. Government of Canada, Province of British Columbia, Victoria, B.C. 197p.

Field, R. and R.E. Pitt. 1990. Urban storm induced discharge impacts: US Environmental Protection Agency research program review. Water Sci. Technol. 22:10-11

Fielden, R.J. and L.B. Holtby. 1987. Stranding crop and habitat characteristics of juvenile salmonids at sites in the Cowichan River system. Can. MS Rep. Fish. Aquat. Sci. 1950. 65p.

Finkenbine, J.K., J.W. Atwater, and D.S. Mavinic. 2000. Stream health after urbanization. J. Am. Water Resour. Assoc. 36(5)1149-1160.

Finnigan, R.J. 1978. A study of fish movement stimulated by a sudden reduction in rate of flow. Fish. Mar. Serv. Data Rep. No 97. 3p.

Fitch, L. and B.W. Adams. 1998. Can cows and fish co-exist? Can. J. Plant Sci. 78(2):191-198.

Fleming, J.O. J.S. Nathan, C. McPherson, and C.D. Levings. 1987. Survey of juvenile salmonids in gravity-fed irrigation ditches, Nicola and Coldwater River valleys,1985. Can. Data Rep. Fish. Aquat. Sci. no. 622, 50p.

Foerster, R.E. and W.W. Ricker. 1953. The coho salmon of Cultus Lake and Sweltzer Creek. J. Fish. Res. Board Can. 10(6):293-319.

Folmar, L.C., H.O. Sanders and A.M. Julin. 1979. Toxicity of the herbicide glyphosate and several of it formulation to fish and aquatic invertebrates. Arch. Environ. Contam. Toxicol., 8(3):269-278.

Ford, J.E. and D.G. Lonzarich. 2000. Over-winter survival and habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in two Lake Superior tributaries. J. Great Lakes Res. 26(1):94-101.

Foreman, R.T. and L.W. Alexander. 1998. Roads and their major ecological effects. Annu. Rev. Ecol. Syst. 29:207-31.

Franklin, J.F. F.J. Swanson and J.R. Sedell. 1982. Relationship within the valley floor ecosystems in Western Olympic National Park: a summery. Pages 43-45, *In* E.E. Starkey, J.F. Franklin, J.W.Matthews (eds) Ecological research in national parks of the pacific northwest: Proceedings, 2d conference on scientific research in the national parks. Oregon State University Forest Research Laboratory.

Fraser River Action Plan. 1998. Urban Issues. Contract Report. for Environment Canada, Vancouver, B.C. ISBN# 0-662-26936-5. 37p. http://www.ncr.dfo.ca/communic/cread/english/Links/Reports/98-99/Fraser%20River/FRAP-EN.HTMl

Fraser, F.J., P.J. Starr, and A.Y. Fedorenko. 1982. A review of the chinook and coho salmon of the Fraser River. Can. Tech. Rep. Fish, Aquat. Sci. 1126:130p.

Friesen, W. 1990. Winter dietary studies of juvenile coho salmon (*Oncorhynchus kisutch*) utilizing two enhanced wall-base channels along the Clearwater River in Jefferson County, Washington. Thesis, Master of Environmental Studies, Evergreen State College, Olympia, Washington. 114p.

Funk, J.L and C.E. Ruhr. 1971. Stream channelization in the midwest. pages 5 –11, In Edw. Schneberger and J.L. Funk, (eds), Stream Channelization a Symposium. North Central Division American Fisheries Society Special Publication No. 2..

Gaikowski, M.P. S.J. Hamilton, K.J. Buhl, S.F. McDonald and C.H. Summers. Acute toxicity of three fire-retardant and two fire-suppressant foam formulatiojns to the early life stages of rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 15(8):1365-1374.

Garrett, A.M. 1998. Interstream movements of coastal cutthroat trout (*Oncorhynchus clarki clarki*) in the Clearwater River, Jefferson County, Washington. Thesis, Master of Environmental Studies, Evergreen State College, Olympia, Washington. 212p.

Giannico R.G. 1995. Juvenile coho salmon habitat utilization and distribution in a suburban watershed: The Salmon River (Langley, B.C). PhD. thesis. Resource management and Environmental Studies Programme. Univ. of British Columbia, Vancouver, B.C. 221p.

Giannico, G.R., and M.C. Healey, 1998. Effects of flow and food on winter movements of juvenile coho salmon. Trans. Amer. Fish. Soc. 127:645-651.

Glavin, T. 1997. Coho in the culvert. Canadian Geographic. 117(3):46-55.

Glova, J.G. 1978. Patterna and mechanism of resource partitioning between stream populations of juvenile coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Salmo clarki clarki*). PhD. Thesis. Institute of Animal Resource Ecology, University of British Coumbia. 185p.

Glova G.F. 1984. Management implication of the distribution and diet of sympatric population of juvenile coho salmon and coastal cutthroat trout in small streams in British Columbia, Canada. Prog. Fish-Cult. 46:269-277.

Graham, C.C. and L.R. Russell. 1979. An investigation of juvenile salmonid utlization of the delta-lakefront area of the Adams River, Shuswap Lake. Can. Fish. Mar. Serv. MS Rep. 1508:32p

Gregory, J.S. and J.S. Griffith. 1996. Winter concealment by subyearling rainbow trout: Space size selection and reduced concealment under surface ice and in turbid water conditions. Can. J. Zool. 74(3):451-455.

Gregory, S.V., F.J. Swanson, W.A. McKee and K.W. Cummins. 1991. An ecosystem perspective of riparian zones, Bioscience 41:540-551.

Griffiths, J.S. and D. F. Alderdice. 1972. Effects of acclimation and acute temperature on the swimming speed of juvenile coho salmon. J. Fish. Res. Bd. Can. 29:251-264.

Griffith, J. S. and R.W. Smith. 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the south fork of the Snake River, Idaho. North Am. J. Fish. Manage. 13:823-830.

Grizzell, R.A. 1976. Flood effects on stream ecosystems. Journal of soil and water conservation. Vol 31, No 6. pp. 283-285.

Golding, D.L. and R.H. Swanson. 1978. Snow accumulation and melt in samll forest openings in Alberta. Can. J. For. Res. 8:380-388.

Goodman, D. 1975. Fisheries resources and foodweb components of the Fraser River estuary and an assessment of the impacts of proposed expansion of the Vancouver International Airport and other developments of the Vancouver International Airport and other developments on these resources. Environ. Can., Fish. Mar. Serv., Vancouver, B.C. 134p.

Gucinski, H., M.J. Furniss, R.R. Ziemer, M.H. Brookes. 2001. Forest roads: a synthesis of scientific information. Gen. Tech. Rep. PNW-GTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Nothwest Research Station. 103p.

Gudkov, P.K. 1996. Formation of the life strategy of Dolly Varden char *Salvelinus malma* at different latitudes. J. Ichthyol. (36(5):376-384.

Haapala, A. T. Muotka, and A. Markkola. 2001. Breakdown and macroinvertebrate and fungal colonization of alder, birch, and willow leaves in a boreal forest stream. J. N. Am. Benthol. Soc. 20(3):395-407.

Habitat Work Group. 1978. Fraser River Estuary Study: Habitat Vol 4. Government of Canada. Report of the Habitat Work Group ISBN 0-7719-8092-2 181p..

Hagen, M.E. 1990. Agricultural runoff contamination in the Fraser River Estuary: Discussion paper. Fraser River Estuary Management Program (Canada; Waste Management Activity Program Working Group, New Westminister, BC (Canada). 54p.

Hagen, M.E. 1992. Potential surface water contamination from miscellaneous sources in the Fraser River Estuary: Background paper. Fraser River Estuary Management Program, Waste Management Activity Program Working Group. (Abstract only).

Hall, J. D. and N.J. Knight. 1981. Natural variation in abundance of salmonid populations in streams and its implications for design of impact studies. A review. Corvallis Environmental Research Lab., Oregon. 85p.

Hall, K.J. and H. Schreier. 1996. Urbanization and agricutural intensification in the Lower Fraser River valley: Impacts on water use and quality. GeoJournal 40 (1-2):135-146. (Abstract only)

Halupka, K.C. M.D. Bryant, F.M. Willson, and F.H Everest. 2000. Biological characteristics and population status of anadromous salmon in south-east Alaska. Gen. Tech. Rep. PNW-GTR-468. Portland, OR: U.S Department of Agriculture, Forest Service, Pacific Northwest Research Station. 255p.

Hamilton, R. and J.W. Buell. 1976. Effects of modified hydrology on Campbell River salmonids. Technical report series PAC/T, (Can. Fisheries and Marine Service. Pacific Region: 76-20:177p.

Harper, D.J. and J.T. Quigley. 2000. No net loss of fish habitat: an audit of forest road crossings of fish-bearing streams in British Columbia, 1996-1999. Can. Tech. Rep. Fish. Aquat. 2319. 50p.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V.Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr. and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems, p. 133-302. In A. MacFadyen and E.D. Ford [ed.]. Advances in Ecological Research 15:436p. Academic Press, Orlando, FL.

Harr, M.D., A. Levno and R. Mersereau. 1982. Streamflow changes after logging 130-year-old Douglas-fir in two small watersheds. Water Resources Research 18(3):637-644.

Harr, R.D. 1976. Hydrology of small forest streams in western Oregon. USDA. Forest service general technical report, PNW-55. 15p.

Harr, R.D. 1981. Some characteristics and consequences of snowmelt during rainfall in Western Oregon. J. Hydrol., 53:277-304.

Harr, R.D. and F.M. McCorison. 1979. Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon. Water Resources Research 15(1):90-94.

Harr, R.D. and S.N. Berris. 1983. Snow accumulation and subsequent melt during rainfall in forested and clearcut plots in western Oregon. Proceedings of the 51st Annual Western Snow Conference, Vancouver, Washington. pp.38-45.

Harr, R.D., W.C. Harper, J.T. Krygier, and F.S. Hsieh. 1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. Water. Resour. Res. 11:436-44.

Hartman, G.F. 1965. The role of behaviour in the ecology and interaction of underyearling coho salmon (*Oncorhyncus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 20:1035-1081.

Hartman, G.F. and C.A. Gill. 1968. Distributions of juvenile steelhead and cutthroat trout (*Salmo gairdneri* and *S. clarki clarki*) within streams in southwestern British Columbia. J. Fish. Res. Bd. Can. 25:33-48.

Hartman, G.F. and J.C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Can. Bull. Fish. Aquat. Sci. 223:148p.

Hartman, G.F., and R.M. Leahy. 1983. Some temperature characteristics of stream and intergravel water in Carnation Creek, British Columbia. Can. MS. Rep. Fish. Aquat. Sci. 1731:40p.

Hartman, G.F. and T.G. Brown. 1987. The use of small, temporary, flood-plain tributaries by juvenile salmonids in a west coast rain-forest drainage basin, Carnation Creek, British Columbia. Can. J. Fish. Aquat, Sci. 44:262-270.

Hartman, G.F. and T.G. Brown. 1988. Forestry-Fisheries planning considerations on coastal flood-plains. Forestry Chronicle Feb. p47-51.

Hartman, G.F., J.C. Scrivener, and M.J. Miles. 1996. Impacts of logging in Carnation Creek, a high energy coastal stream in British Columbia, and their implications for restoring fish habitat. Can. J. Fish. Aquat. Sci. 53:237-251.

Hartman, G.F., J.C. Scrivener, M.J. Brownlee, and D.C. Morrison. 1983. Fish habitat protection and planning for forest harvesting in coastal streams of British Columbia: some research and management implications. Canadian Industry Report of Fisheries and Aquatic Sciences No. 143. 71p.

Harvey, B.C. 1987. Susceptibility of young-of-the-year fishes to downstream displacement by flooding. Trans. Am. Fish. Soc. 116:851-855.

Harvey, B.C., R.J. Nakamoto, and J.L. White. 1999. Influence of large woody debris and a bankfull flood on movement of adult resident coastal cutthroat trout (*Oncorhynchus clarki*) during fall and winter. Can. J. Fish. Aquat. Sci. 56:2162-2166.

Hawkins, D.K. and T.P. Quinn. 1996. Critical swimming velocity and associated morphology of juvenile coastal cutthroat trout (*Oncorhynchus clarki clarki*), steelhead trout (*Oncorhynchus mykiss*) and their hybrids. Can. J. Fish. Aquat. Sci. 53:1487-1496.

Headrick, M.R. Effects of stream channelization of fish population in the Buena Vista Marsh, Portage county, Wisconsin. Fish and Wildlife Service, U.S. Dept of the Interior. FWS/OBS;76/24. 38p.

Healey, M.C. 1979a. Detritus and juvenile salmon production in the Nanaimo Estuary: 1. Production and feeding rates of juvenile chum salmon (*Oncorhynchus keta*). J. Fish Res. Board Can., 36(5):488-496.

Healey, M.C. 1979b. Utilization of the Nanaimo river estuary by juvenile chinook salmon. *Oncorhynchus tshawytscha*. Fish. Bull. 77(3):653-668.

Healey, M.C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 39:952-957.

Healey, M.C. 1983. Coastwide distribution and ocean migration patterns of stream- and ocean-type chinook salmon (*Oncorhynchus tshawytscha*). Can. Field Naturalist 97:427-433.

Healey, M.C. 1991. Life history of chinook salmon pink salmon (*Oncorhynchus tshawytscha*). Pages 311-394, *In* C. Groot and L. Margolis (ed), Pacific Salmon Life Histories. University of British Columbia Press, Vancouver, B.C.

Heard, W.R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pages 119-230, in C. Groot and L. Margolis (ed), Pacific Salmon Life Histories. UBC Press, Vancouver, Canada.

Heggenes, J., T.G. Northcote, and A. Peter. 1991a. Seasonal habitat selection and preferences by cutthroat trout (*Oncorhynchus clarki*) in a small coastal stream. Can. J. Fish. Aquat. Sci. 48(8):1364-1370.

Heggenes, J. T.G. Northcote, and A. Peter. 1991b. Spatial stability of cutthroat trout (*Oncorhynchus clarki*) in a small coastal stream. Can. J. Fish. Aquat. Sci. 48(5):757-762.

Heggenes, J., O.M.W. Krog, O.R. Lindas, J.G. Dokk, and T.Bremnes. 1993. Homeostatic behavioural responses in a changing environment: brown trout (*Salmo trutta*) become nocturnal during winter. J. Anim. Ecol. 62:295-308.

Heifetz, J., M. L. Murphy, and K.V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. North American Journal of Fisheries Management 6:52-58.

Henderson, M.A. 1991. Sustainable development of the Pacific salmon resources in the Fraser River Basin. Pages 133-154 *in* A.H.J. Dorcey (*ed*). Perspectives on sustainable development in water management: towards agreement in the Fraser River Basin. Westwater Research Centre, U.B.C. Vancouver, B.C., Canada.

Henderson, M.A. and A.J. Cass. 1991. Effect of smolt size on smolt-to-adult survival for Chilko Lake sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 48(6):988-994.

Hetherington E.D. 1982. A first look at logging effects on the hydrologic regime of Carnation creek experimental watershed. Pages 43-53 *in* G.F. Hartman (ed), Proceedings of the Carnation Creek Workshop, 10 year review. Nanaimo. B.C. Pacific Biological Stn.

Hetherington, E.D. 1985. Streamflow nitrogen loss following forest fertilization in a southern Vancouver Island watershed. Can. J. For. Res. 15(1):34-41.

Hetherington, E.D. 1987. The importance of forest in the hydrological regime. Pages 179-211 in Healey, M.C. and R.R. Wallace (ed) Canadian aquatic resources. Can. Bull. Fish. Aquatic Sci. 215:533p.

Hetherington, E.D. 1988. Hydrology and logging in the Carnation Creek watershed – what have we learned? Pages 11-15, *in* T.W. Chamberlin (ed), Applying 15 years of Carnation Creek results: Proceeding of the Workshop. Pacific Biological Stn. Nanaimo, British Columbia.

Hetherington, E.D. 1989. Carnation Creek Floodplain Hydrology September 1984-September 1985. Pages 27-43, *in* Reynolds, P.E. (ed). Proceedings of the Carnation Creek Herbicide Workshop, Nanaimo, B.C. by Ministry of Forests, Research Branch.

Hewlett, J. D. 1982. Principles of Forest Hydrology. University of Georgia Press, Athens, Georgia. 183p.

Higgins, P.S. and M.J. Bradford. 1996. Evaluation of a large-scale fish salvage to reduce the impacts of controlled flow reduction in a regulated river. N. Am. J. Fish. Manage. 16(3)666-673.

Hilderbrant, R.H. and J.L. Kershner. 2000. Movement patterns of stream-resident cutthroat trout in Beaver Creek, Idaho-Utah. Trans. Am. Fish. Soc. 129(5):1160-1170.

Hillman, T.W., J.S.Griffith, and W.S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Trans. Amer. Fish. Soc. 116:185-195.

Hirst, S.M. 1991. Impacts of operation of existing hydroelectric developments on fishery resources in British Columbia. Volume 1. Anadromous salmon. Can. Manuscr. Rep. Fish. Aquat. Sci., No. 2093, 153p.

Hoar, W.S., 1958. The evolution of migratory behaviour among juvenile salmon of the genus *Oncorhynchus*. J. Fish. Res. Bd. Canada, 15(3):391-428.

Hogan, M. 1987. Stream channelization and its effects on fish habitat. Canada Dept. Fisheries and Oceans. Newfoundland Region. Fisheries and Habitat Management Branch. 38p.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can J. Fish. Aquat. Sci. 45:502-515.

Holtby, L.B. 1989. Changes in the temperature regime of a valley-bottom tributary of Carnation Creek, British Columbia, over-sprayed with the herbicide Roundup (Glyphosate). Pages 212-223 *in* Reynolds, P.E. (ed). Proceedings of the Carnation Creek Herbicide Workshop, Nanaimo, B.C. by Ministry of Forests, Research Branch.

Holtby, L.B. and S.J. Baillie. 1989. Effects of the herbicide roundup on coho salmon fingerlings in an over-sprayed tributary of Carnation Creek, British Columbia. Pages 273-285 *in* Reynolds, P.E. (ed). Proceedings of the Carnation Creek Herbicide Workshop, Nanaimo, B.C. by Ministry of Forests, Research Branch.

Holtby, L.B., B.C. Andersen, and R.K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 47(11)2181-2194.

Horner, R.R., D.B. Booth, M.A. Azous and C.W. May. 1995. Watershed determinants of ecosystem functioning. Draft report prepared for L.A. Roesner (*ed*). Effects of Watershed Development and Management on Aquatic Ecosystems. 27p.

Hudson, R. 2002. Effects of forest harvesting and regeneration on peak streamflow in a coastal watershed. Forest Research Technical Report. TR-022:40p

Huet, M. and J.A. Timmermans (eds). 1976. Effects of channelization on the fish population in small streams with a rather rapid flow. D Hydrobiol. 46 (Abstract Only).

Hume, J. S. MacLellan, and K. Shortreed. 2000. Comparison of fishing gears in different habitat types in Harrison Lake – 2000 Progress Report. Internal document, Fisheries and Oceans, Cultus Lake Salmon Research Laboratory. 10p.

Humphries, P., A.J. King and J.D. Koehn. 1999. Fish, flows and floodplains: links between freshwater fishes and their environment in the Murry-Darling River system, Australia. Environmental Biology of Fishes 56(1-2):129-151. (Abstract Only).

Hunt, R.L. 1969. Effects of habitat alteration on production, standing crop, and yield of brook trout in Lawrence Creek, Wisconsin. *In* pages 281-312, T.G. Northcote (ed.) Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, Institute of Fisheries, University of British Columbia, Vancouver, British Columbia, Canada.

Hylander, K., C. Nilsson, B.G. Jonsson, and C. Nilsson. 2002. Evaluating buffer strips along boreal streams using bryophytes as indicators. Ecological Applications. 12(3):797-806.

Imhof, J., J. Planck, F. Johnson and L. Halyk. 1991. Watershed urbanization and managing stream habitat for fish. 56th North American Wildlife and Natural Resources Conference. 35p.

IRC Integrated Resource Consultants Inc. 1994. Agricultural land use survey in the Sumas River watershed summary report. Report prepared for B.C. Ministry of Environment, Lands and Parks and Department of Fisheries and Oceans, Fraser River Environmentally Sustainable Development Task Force, Vancouver, B.C. 105p.

Irons, J.G. III, Miller, L.K., and Oswood, M.W. 1993. Ecological adaptations of aquatic macroinvertebrates to over-wintering in interior Alaska (U.S.A.) subartic streams. Can. J. Zool. 71:98-108.

Irvine, J.R. 1985. Effects of successive flow perturbations on stream invertebrates. Can. J. Fish. Aquat. Sci. 42:1922-1927.

Irvine, J.R. 1986. Effects of varying discharge on the downstream movement of salmon fry, Oncorhynchus tshawytscha Walbaum. J. fish. Biol. 28:17-28.

Irvine, J.R. 1987. Effects of varying flows in man-made streams. Pages 83-97, *In* J.T. Craig and J.B. Kemper (ed.) Regulated Streams, Plenum Publishing Corporation.

Irvine J.R. and N.T. Johnston. 1992. Coho salmon (*Oncorhynchus kisutch*) use of lakes and streams in the Keogh River drainage, British Columbia. Northwest Science, Vol. 66(1):15-25.

Iritz, L, B. Johansson and L. Lundin. 1994. Impacts of forest drainage on floods. Hydrological Sciences Journal. Vol.39, No. 6. Pp. 637-662.

Jakober, M.J., T.E. McMahon and R.F. Thurow. 2000. Diel habitat partitioning by bull charr and cutthroat trout during fall and winter in rocky Mountain steams. Environ. Biol. Fish. 59(1):79-89.

Jakober, M.J., T.E. McMahon, R.F. Thurow, and C.G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Trans. Am. Fish. Soc. 127(2):223-235.

Jansen, A. and A.I. Robertson. 2001. Relationships between livestock management and ecological condition of riparian habitats along an Australian floodplain river. J. Appl. Ecol. 38(1):63-75.

Janz, D.M., A.P. Farrell, J.D. Morgan, G.A. and G.A. Vigers. 1991. Acute physiological stress responses of juvenile coho salmon (Oncorhynchus kisutch) to sublethal concentrations of Garlon 4, Garlon 3A and Vision herbicides. Environ. Toxicol. Chem. 10(1):81-90.

Jenks, S.P. 1989. Stillaguamish River coho salmon (*Oncorhynchus kisutch*) off-channel, habitat enhancement project. *In* B.G. Shepherd (ed), Proceedings of the 1988 Northeast Pacific chinook and coho salmon workshop. Bellingham Washington. Pages 148-155.

Jensen, A.J. and B.O. Johnsen. 1999. The functional relationship between peak spring floods and survival and growth of juvenile Atlantic Salmon (*Salmo salar*) and Brown Trout (*Salmo trutta*). Functional Ecology 13(6):778-785.

Johnston, J.H. and N.H. Ringler. 1980. Diets of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*) relative to prey availability. Can. J. Zool. 58(4)553-558.

Johnson, J.H. and P.A. Kucera. 1984. Summer-autumn habitat utilization of subyearling steelhead trout in tributaries of the Clearwater River, Idaho. Can. J. Zool. 63:2283-2290.

Johnson, S.W., J.F. Thedinga, and A.S. Feldhausen. 1994. Juvenile salmonid densities and habitat use in the main-stem Situk River, Alaska, and potential effects of glacial flooding. Northwest Science. 68(4):284-293.

Johnston, N.T., J.R. Irvine, and C.J. Perrin. 1987. Coho salmon (*Oncorhnchus kisutch*) utilization of tributary lakes and streams in the Keogh River drainage, British Columbia. Can. MS Rep. Fish. Aquat. Sci. 1973: 54p.

Jones, J.A. and G.E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large Basins, Western Cascades, Oregon. Water Resources Research 32(4):959-974.

Jong, E. de and R.G. Kachanoski. 1987. The role of grasslands in hydrology. Pages 213-241 *in* Healey, M.C. and R.R. Wallace (ed) Canadian aquatic resources. Can. Bull. Fish. Aquatic Sci. 215:533p.

Kahler, T.H., P.Roni, and T.P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Can. J. Fish. Aquat, Sci. 58(10):1947-1956.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications: A review. J. Range Manage. 37(5):430-438.

Kauffman, J.B., W.C. Krueger and M. Vavra. 1983. Impacts of cattle on streambanks in north-eastern Oregon. J. Range Manage. 36(6);683-684.

Kauffman, J.B., R.L. Beschta, N. Otting, and D. Lytjen. 1997. An ecological prespective of riparian and stream restoration in the western United States. Fisheries, Special Issue on Watershed Restoration. 22(5):12-24.

Keenan, R.J., and Kimmins, J.P. 1993. The ecological effects of clear-cutting. Environ. Rev. 1: 121-144.

Kelly, D.J., Clare, J.J., and M.L. Bothwell. 2001. Attenuation of ultraviolet radiation by dissolved organic matter alters benthic colonization patterns in streams. J. N. Am. Benthol. Soc. 20(1):96-108.

Kelly, D.J. and M.L. Bothwell. 2002a. Avoidance of solar ultraviolet radiation by juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. and Aquat. Sci. 59(3):474-482.

Kelly, D.J. and M.L. Bothwell. 2002b. Effects of solar radiation on shallow stream invertebrates. National Institute of Water and Atmospheric Research, Christchurch, New Zealand. 3p. http://www.niwa.cri.nz/pubs/wa/10-2/staffpubs

Kishi, C. F. Nakamura, and M. Inoue. 1999. Budgets and retention of leaf litter in Horonai Steam, southwestern Hokkaido, Japan. Jap. J. Ecol. 49(1):11-20. (Abstract only)

Kistritz, R.U. 1996. Habitat compensation, restoration and creation in the Fraser River estuary – Are we achieving a no-net loss of fish habitat? Can. Man. Rep. of Fish. and Aquat. Sci. No. 2349.

Kistritz, R.U. and J.S. Macdonald. 1990. Environmental research on fish habitat restoration at Tilbury Slough, Fraser River estuary, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 781. 65p.

Kistritz, R.U., K.J. Scott, and C.D. Levings. 1996. Changes in fish habitat in the lower Fraser River analyzed by two wetland classification systems. Chapter 2. Pages 19-40 *in* C.D. Levings and D.J.H. Nishimura (*ed.*), Created and restored sedge marshes in the lower Fraser River and estuary: An evaluation of their functioning as fish habitat. Can. Tech. Rep. Fish. Aquat. Sci. 2126:143p.

Kistritz, R.U., G.L. Porter, G. Radcliffe, P.R. Ward. 1992. An ecological study of Surrey Bend. Report prepared for Fraser River Estuary management Program and the District of Surrey. 120p.

Kjelson, M.A, and P.F. Raquel. 1981. The life history of fall run juvenile chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin Estuary of California. Estuaries. 4(3):285.

Knight, N.J. 1980. Factors affecting smolt yield of coho salmon (*Oncorhynchus kisutch*) in three Oregon streams. MSc. Thesis Oregon State Univ., Corvallis. 101p.

Kramer, B. 2002. Shuswap Lake Spring Flood Research Project. Report and Database available Internet. webmaster@shuswaplakewatch.com

Kwak, T.J. 1988. Lateral movement and use of floodplain habitat by fishes of the Kankakee River, Illinois. American Midland Naturalist 120(2):241-249. (Abstract only)

Langer, O.E., F. Hietkamp, and M. Farrell. 2000. Human population growth and the sustainability of urban salmonid streams in the lower Fraser Valley. Pages 349-361 *in* E. E. Knudsen, C.R.

Steward, D.D MacDonald, J.E. Williams and D.W. Reiser, (eds), Sustainable Fisheries Management: Pacific Salmon. Lewis Publishers, Boca Raton, New York.

Lantz, R.L. Guidelines for stream protection in logging operations. Report of the Research Division Oregon State Game Commission 29p.

Lapointe, M., B.Eaton, S. Driscoll and C. Latulippe. 2000. Modelling the probability of salmonid egg pocket scour due to floods. Can. J. Fish. Aquat. Sci. 57(6) 1120-1130.:

Lee, R. 1980. Forest Hydrology. Columbia University Press, New York, New York. 349p.

Leider, S.A., M.W. Chilcote and J.J. Loch. 1986. Movement and survival of presmolt steelhead in a tributary and the main stem of a Washington River. North American Journal of Fisheries Management 6:526-531.

Leidholt-Bruner, K., D.E. Hibbs, W.C. McComb. 1992. Beaver dam locations and their effects on distribution and abundance of coho salmon fry in two coastal Oregon streams. Northwest Science 66(4):218-223.

Leith, R.M. and P.H. Whitfield. 2000. Some effects of urbanization on streamflow records in a a small watershed in the lower Fraser Valley, B.C. Northwest Science. Vol 74, No 1. Pp 69-75.

Lepistoe, L and M. Saura. 1998. Effects of forest fertilization on phytoplankton in a boreal brown-water lake. Boreal Environ. Res. 3(1):33-43. (Abstract only)

Lestelle, L.C. G.R. Blair, and S.A.Chitwood. 1993. Approaches to supplementing coho salmon in the Queets River, Washington. Pages 104-119. *in* L.Berg and P.W. Delaney (eds). Proceedings of the coho workshop, Nanaimo, B.C., May 26-28, 1992.

Levings, C.D. 2000. An overview assessment of compensation and mitigation techniques used to assist fish habitat management in British Columbia estuaries. Pages 341-347 *in* E. E. Knudsen, C.R. Steward, D.D MacDonald, J.E. Williams and D.W. Reiser, (eds), Sustainable Fisheries Management: Pacific Salmon. Lewis Publishers, Boca Raton, New York.

Levings C.D. and D.J.H. Nishimura (ed). 1996. Created and restored sedge marshes in the lower Fraser River and estuary: An evaluation of their functioning as fish habitat. Can. Tech. Rep. Fish. Aquat. Sci. 2126:143p.

Levings, C.D. and G. Jamieson. 2001. Marine and estuarine riparian habitats and their role in coastal ecosystems, pacific Region. DFO Canadian Science Advisory Secretariat Research Document 2001/109. 41p.

Levings, C.D. and R. Lauzier. 1989. Migration patterns of wild and hatchery-reared juvenile chinook salmon (*Oncorhynchus tshawytscha*) in the Nicola River, British Columbia. *In* B.G.

Shepherd (ed), Proceedings of the 1988 Northeast Pacific chinook and coho salmon workshop. Bellingham Washington. Pages 267-275.

Levings, C.D. and R. Lauzier. 1991. Extensive use of the Fraser River basin as winter habitat by juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Zool. 69: 1759-1767.

Levings, C.D. and R.M. Thom. 1994. Habitat changes in Georgia Basin: Implication for resource management and restoration. Pages 330-349 in R.C. Wilson, R.J. Beamish, F. Aitkens and J. Bell (eds), Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment, Can. Tec. Rep. Fish. Aquat. Sci. 1949:398p.

Levings, C.D., D.E. Boyle, and T.R. Whitehouse. 1995. Distribution and feeding of juvenile Pacific salmon in freshwater tidal creeks of the lower Fraser River, British Columbia. Fisheries Management and Ecology. Vol. 2, No. 4, pp.299-308.

Levings, C.D., K. Conlin, and B. Raymond. 1991. Intertidal habitats used by juvenile chinook salmon (*Oncorhynchus tshawytscha*) rearing in the north arm of the Fraser River Estuary. Mar. Pollut. Bull. 22(1):20-26.

Levings, C.D., J.C. Scrivener, B. Andersen, C. Shirvell, and R. Lauzier. 1985. Results of reconnaissance sampling for juvenile salmonids in the upper Fraser River and selected tributaries. August and October, 1984. Can. Data. Rep. Fish. Aquat. Sci. 5439. 25p.

Levno, A. and J. Rothacher. 1967. Increases in maximum stream temperatures after logging in old-growth Douglas-fir watersheds. USDA Forest Service, Pacific Northwest Forest Range and Experimental Station, Research Note PNW-65. 12p.

Levy, D.A. 1992. Potential impacts of global warming on salmon production in the Fraser River watershed. Can. Tech. Rep. Fish. Aquat. Sci. 1889. 96p

Levy, D.A. and C.D. Levings. 1978. A description of the fish community of the Squamish River estuary, British Columbia: relative abundance, seasonal changes, and feeding habits of salmonids. Manuscr. Rep. Fish. Mar. Ser. (Can.) Number 1475. 67p.

Levy, D.A. and T.G. Northcote. 1979. Juvenile salmon utilization of tidal channels in the Fraser River estuary, British Columbia. Westwater Research Centre Technical Report, No. 23. U.B.C. Vancouver, B.C. 117p.

Levy, D.A. and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Lewis, J. 1997. Changes in storm peak flows after clearcut logging. Transactions American Geophysical Union 78(46). Abstract only.

Lewis, A.F.J. and C.D. Levings. 1988. Sampling of juvenile chinook salmon in Slim Creek, Quesnel, Salmon and Eagle Rivers (Fraser River System). Report prepared by Environcon Pacific Limited. 59p + Appendix.

Likens, G.E. and F.H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience 24(4):447-456.

Lindroth, A. 1965. First winter mortality of Atlantic salmon parr in the hatchery. Can. Fish. Cult. 36:23-26.

Lister, D.B. and H.S. Genoe. 1970. Stream habitat utilization by cohabiting under-yearlings of chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) ssalmon in the Big Qualicum River, British Columbia. J. Fish. Res. Board Can. 27:1215-1224.

Lock, J.J., M. W. Chilcote and S.A.Leider. 1985. Kalama River studies final report. Part II: Juvenile downstream migrant studies. Wash. Dep. of Game, Fish. Manage. Div., Olympia. Rep 85-12,

Lucchetti, G. and R. Fuerstenberg. 1993. Management of coho salmon habitat in urbanizing landscapes of King County, Washington, USA. Pages 308-317 *in* L.Berg and P.W. Delaney (eds). Proceedings of the coho workshop, Nanaimo, B.C., May 26-28, 1992.

Luey, J.E. and I.R. Adelman. 1980. Downstream natural areas as refuges for fish in drainage-development watersheds. Trans. Am. Fish. Soc., 109(3):332-335.
Macdonald, J.S. 1994. Intergravel environments. Pages 33 to 37 *in* J.S. Macdonald (*ed*) Proceedings of the Takla Fishery/Forestry Workshop: a two year review. April 1, 1993, Prince George, B.C. Can. Tech. Rep. Fish. Aquat. Sci. 2007:104p.

Macdonald, J.S., I.K. Birtwell, and G.M. Kruzynski. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Can. J. Fish. Aquat. Sci. 44:1233-1246.

Macdonald, J.S.. J.C. Scrivener, and G. Smith. 1992. The Stuart-Takla Fisheries/Forestry Interaction Project: Study Description and Design. Can. Tech. Rep. Fish. Aquat. Sci. 1899:39.

Macdonald, J.S., R.U. Kistritz and M. Farrell. 1990. An examination of the effects of slough habitat reclamation in the Lower Fraser River, British Columbia: Detrital and invertebrate flux, rearing and diets of juvenile salmon. Can. Tech. Rep. Fish. Aquat. Sci. 1731: 59p.

Macdonald, R.W., E.C. Carmack and C.H. Pharo. 1994. Sediment records of man's activities in the Kootenay Lake drainage basin. Water Pollut. Res. J. Can. 29(1):103-116.

MacKenzie, F.B. 1987. Urbanization and hydrological regime. Pages 277-293 *in* M.C. Healey and R.R. Wallace (eds). Canadian Aquatic Resources. Canadian Bulletin of Fisheries and Aquatic Sciences 215. 533p.

McArthur, M.D. and J.S. Richardson. 2002. Microbial utilization of dissolved organic carbon leached from riparian litterfall. Can. J. fish. Aquat. Sci. 59(10):1668-1676.

McCain, M.E. 1989. Natal stream rearing habitat of juvenile chinook saln in Hurdygurdy Creek, California. *In* B.G. Shepherd (ed.), Proceedings of the 1988 Northeast Pacific chinook and coho salmon workshop. Bellingham, Washington. Pages 136-140.

McDonald, J. 1960. The behaviour of pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. J. Fish. Res. Bd. Canada, 17(5).

McIntosh, B.A.; J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves, L.A. Brown. 1994. Management history of eastside ecosystems: changes in fish habitat over 50 years, 1935 to 1992. Gen. Tech. Rep. PNW-GTR-321. Portland, Or: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55p.

Maciolek, J.A. and P.R. Needham. 1952. Ecological effects of winter conditions on trout and trout food in Convict Creek, California, 1951. American Fisheries Society 81:202-217.

McLean, D.G. 1990. The relation between channel instability and sediment transport on the lower Fraser River. PhD thesis, University of British Columbia, Dept of Geography.

McLeay, M.J. and K.J. Hall. 1999. Monitoring agricultural drainage ditches and receiving water (Nicomekl River, Surrey, B.C.) for toxicity to *Ceriodaphnia dubia* and probable cause due to organophosphate contamination. Water Qual. Res. J. Can. 34(3):423-453.

McMahon, T.E., and G.F. Hartman. 1988. Variation in the degree of silvering of wild coho salmon (*Oncorhynchus kisutch*) smolts migrating seaward from Carnation Creek, British Columbia. J. Fish. Biol. 32:825-833.

McMahon, T.E., and G.F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 46:1551-1557.

Marcus, M.D., M.K Young, L.E. Noel, B.A. Mullan. 1990. Salmonid-habitat relationships in the western United States. Gen. Tech. Rep. RM-188. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experimental Station. 84p.

Marmulla, G. 2001. Dams, fish and fisheries: opportunities, challenges and conflict resolution. FAO fisheries technical paper 419. 165p. (Abstract only).

Martel, G. 1996. Growth rate and influence of predation risk on territoriality in juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 53(3):660-669.

Marshall, DE. and E.W. Britton. 1990. Carrying capacity of coho salmon streams. Canadian Manuscript Report of Fisheries and Aquatic Sciences, 2058:38 pp.

Martin, C.W., J.W. Hornbeck, G.E. Likens, and D.C. Buso. 2000. Impacts of intensive harvesting on hydrology and nutrient dynamics of northern hardwood forests. Can. J. Fish. Aquat. Sci. 57(Suppl. 2) 19-29.

Maser, C. and J.R. Sedell. 1994. From the Forest to the Sea, The Ecology of Wood in Streams, Rivers, Estuaries, and Oceans. St Lucie Press, Delray Beach, FL. 200p.

Mason, J.C. 1974. Aspects of the ecology of juvenile coho salmon (Oncorynchus kisutch) in Great Central Lake, B.C. Fisheries Research Board of Canada, Technical Report 438. 37p.

Mattson, A., J. Li and K. Sherman. Urban stormwater management strategy for the Severn Sound remedial action plan. Water Qual. Res. J. Can. 35(3):475-488.

Melone, A.M. 1985. Flood producing mechanisms in coastal British Columbia. Canadian Water Resources Journal 10(3):46-64.

Metcalfe, N.B. and J.E. Thorpe. 1992. Anorexia and defended energy levels in over-wintering juvenile salmon, *Salmo salar*. J. Anim Ecol. 61:175-181.

Metcalfe, N.B., F.A. Huntingford and J.E. Thorpe. 1986. Seasonal changes in feeding motivation of juvenile Atlantic salmon (*Salmo salar*) Can. J. Zool. 64:2439-2446.

Merritt, R.W. and D.L. Lawson. 1978. Leaf litter processing in floodplain and stream communities. Pages 93-105, In R.R. Johnson and J.F. McCormick (ed.), Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Proceeding of the Symposium 1978, Callaway, Georgia. General Technical Report WO-12. U.S. Department of Agriculture (Forest Service) Washington, D.C.

Meyer, K.A. and J.S. Griffith. 1997. First-winter survival of rainbow trout in the Henrys Fork of the Snake River, Idaho. Can. J. Zool. 75:59-63.

Michael, J.H. Jr. 1989. Life history of anadromous coastal cutthroat trout in Snow and Salmon creeks, Jefferson County, Washington, with implications for management. Calif. Fish Game. 75(4):188-203.

Millar, J., N. Page, M. Farrell, B. Chilibeck and M. Child. 1997. Establishing fisheries management and reserve zones in settlement areas of coastal British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2351:60p

Millar, R.G. and M.C. Quick. 1993. Effect of bank stability on geometry of gravel rivers. J. Hydraulic Eng. 119:1343-1363. (Abstract only)

Millar, R.G. and M.C. Quick. 1998. Stable width and depth of gravel-bed rivers with cohesive banks. J. Hydraulic Eng. 124:1005-1013. (Abstract only)

Miller, J.A. and C.A. Simenstad. 1997. A comparative assessment of a natural and created estuarine slough as rearing habitat for juvenile chinook and coho salmon. Estuaries. 20(4):792-806.

Minakawa, N. and G.F. Kraft. 1999. Fall and winter diets of juvenile coho salmon in a small stream and an adjacent pond in Washington State. J. Freshwat. Ecol. Vol. 14, No. 2, pp. 249-254.

Missler, H. 1992. A bibliography of scientific information on Fraser River basin environmental quality. Environment Canada, Conservation and Protection, Environmental Conservation Directorate. Pacific and Yukon Region Vancouver, B.C. 390p (Abstract only)

Missler H. 1994. A bibliography of scientific information on Fraser River basin environmental quality, 1994 supplement. Environment Canada, Conservation and Protection, Environmental Conservation Directorate. Pacific and Yukon Region Vancouver, B.C. Fraser River Action Plan 1994-11. 173p.

Moore, K.E. 1990. Urbanization in the lower Fraser Valley, 1980-1987. Technical report series Canadian Wildlife Service No. 120. 12p.

Morgan, A. 1996. Winter habitat utilization by juvenile salmonids: a literature review. Unpublished Report. Northwest Indian Fisheries Commission, Grays Harbor College. 24p.

Morrison, J. 2002. Climate change in the Fraser River watershed: 1912-2099. Abstract only of talk given at Science Symposium 2002, Fisheries and Oceans Canada, Nanaimo, B.C. May 2002.

Moscrip, A.A. and D.R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Pudget lowland streams. J. Am. Water Resour. Assoc. Vol. 33, No. 6, pp. 1289-1297.

Mueller, C. and R. Kent. 1988. Downstream fry enumeration of the 1985 brood sockeye and chinook escapement to the Horsefly River. Can. MS Rep. Fish. Aquat. Sci. No. 1980. 38p.

Mundie, J.H. 1974. Optimization of the salmonid nursery stream. J. Fish. Res. Board. Can. 31:1827-1837.

Mundie, J.H. 1991. Perspectives: Overview of effects of pacific coast river regulation on salmonids and the opportunities for mitigation. Am. Fish. Soc. Symp. 10:1-11.

Mundie, J.H. and R. Bell-Irving. 1986. Predictability of the consequences of the kemano hydroelectric proposal for the natural salmon populations. Can. Water Resour. J. 11(1):14-25.

Mundie, J.H. and R.E. Traber. 1983. Carrying capacity of an enhanced side-channel for rearing salmonids. Can. J. Fish. Aquat. Sci. 40(8) 1320-1322.

Murphy, M.L. and J.D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Can. J. Fish. Aquat. Sci. 38:137-145.

Murphy, M.L., and K.V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implication for streamside management. N. Am. J. Fish. Manage. 9:427-436.

Murphy, M.L., K.V. Koski, J.M. Lorenz, and JF. Thedinga. 1997. Downstream migrations of juvenile Pacific salmon (*Oncorhynchus* spp.) in a glacial transboundary river. Can. J. Fish. Aquat. Sci. 54(12):2837-2846.

Murphy, M.L., J. Heifetz, J.F. Thedinga, S.W. Johnson, and K.V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, southeast Alaska. Can. J. Fish. Aquat. Sci. 46:1677-1685.
Murray C.B. and M.L. Rosenau. 1989. Rearing of juvenile chinook salmon in nonnatal tributaries of the lower Fraser River, British Columbia. Trans. Am. Fish. Soc. 118:284-289.

Murray, P.R., S.R. Hamilton and G.O. Stewart. 1981. Studies on juvenile chinook salmon (*Oncorhynchus tshawytscha*) in the Bowron and Willow rivers, B.C. during 1980. DSS Contract No. 07SB.FP501-9-1290. 86p.

Naiman, R.J., D.M. McDowell, and B.S. Farr. 1984. The influence of beaver (*Castor canadensis*) on the production dynamics of aquatic insects. Proceedings of the 22nd Congress of the International Association of Liminology (Lyon, France) 22(3):1801-1810. Abstract only.

Naiman, R.J., R.E. Bilby, and P.A. Bisson. 2000. Riparian ecology and management in the Pacific Coastal Rain Forest. Bioscience 50(11):996-1011.

Nassichuk, M.D., P.G. Futer, J.H. Patterson, and I.K. Birtwell. 1984. Water and sediment chemistry characteristics of the Tilbury and Deas Slough regions of the Fraser River. Can. Data Rep. Fish. Aquat. Sci. 492:81p

Neave, F. 1955. Notes on the seaward migration of pink and chum salmon fry. J. Fish. Res. Bd. Canada. 12(3):369-374.

Neaves, P.I. 1978. Litter fall, export, decomposition, and retention in Carnation Creek, Vancouver Island. Fish. and Mar. Serv. Tech. Rep. No. 809.45p.

Nechako River Project. 1987. Studies of juvenile chinook salmon in the Nechako River, British Columbia – 1985 and 1986. Can. Manuscr. Rep. Fish. Aquat. Sci. 1954:152p.

Nener, J. and K. Brock. 2001. Overview of impacts to fish and wildlife habitat from the development of cranberry farms in South Western British Columbia. Report prepared by Precision Identification Biological Consultants, 3622 West 3rd Ave. Vancouver, B.C. 68p + Maps.

Nicieza, A.G. and F. Brana. 1993. Compensatory growth and optimum size in one-year-old smolts of Atlantic salmon (*Salmo salar*). Pages 225-237, in R.J. Gibson and R.E. Cutting (eds), Can. Spec. Publ. Fish. Aquat. Sci. No. 118. (Abstract only).

Nickelson, T.E., J.D. Rodgers, S.L. Johnson, and M.F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49(4):783-789.

Nielsen, J.L. 1992. Microhabitat-specific foraging behaviour, diet and growth of juvenile coho salmon. Trans. Am. Fish. Soc.. 121:617-634.

Norris, L.A., H.W. Lorz and S.V. Gregory. 1983. 9. Forest chemicals. In W.R Meehan (ed.) Influence of forest and rangeland management on anadromous fish habitat in Western North America. Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Portland, Oregon. 95p.

Northcote, T.G., 1974. Biology of the lower Fraser River: a review. Westwater Research Centre, U.B.C. Tech. Rep. 3:94p.

Northcote, T.G. and G.F. Hartman. 1988. The biology and significance of stream trout populations (*Salmo* spp.) living above and below waterfalls. Pol. Arch. Hydrobiol. 35(3-4):409-442.

Odum 1978. Opening Address: Ecological importance of the riparian zone. Pages 2-4, In R.R. Johnson and J.F. McCormick (ed.), Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Proceeding of the Symposium 1978, Callaway, Georgia. General Technical Report WO-12. U.S. Department of Agriculture (Forest Service) Washington, D.C.

Oliver, J. D. and G.F. Holeton. 1979. Overwinter mortality of fingerling smallmouth bass in relation to size, relative energy stores, and environmental temperature. Trans. Amer. Fish. Soc. 108:130-136.

Osborn, J.G. 1981. The effects of logging on cutthroat trout (*Salmo, clarki*) in small headwater streams. MSc, University of Washnigton, College of Fisheries. 87p.

Paish and Associates. 1981. The implementation of a cooperative watershed planning and management program for the Fraser River watershed – Langley, B.C. Howard Paish and Associates, Vancouver, B.C. 114p.

Panek, F.M. 1979. Cumulative effects of small modifications to habitat. Fisheries 4(2):54-57.

Payne, N., J. Feng and P. Reynolds. Off-targe deposit measurements and buffer zones required around water for various aerial applications of glyphosate. Pages 88-109, *in* Reynolds, P.E. (ed).

Proceedings of the Carnation Creek Herbicide Workshop, Nanaimo, B.C. by Ministry of Forests, Research Branch.

Perrin, C.J., K.S. Shortreed, and J.G. Stockner. 1984. An integration of forest and lake fertilization: Transport and transformations of fertilizer elements. Can J. Fish. Aquat. Sci. 41(2):253-262.

Pert, H.A. 1993. Winter food habitats of coastal juvenile steelhead and coho salmon in Pudding Creek, Northern California. MSc in Wildland Resource Science, University of California at Berkeley. 65p.

Peters, R., E. Knudsen, R. Tabor, and J. Cederholm. 2000. Influence of woody debris on the abundance of juvenile salmonids in large Western Washington Rivers. In International Conference on Wood in World Rivers. Oct 23-27, 2000. Oregon State University, Corvallis, Oregon. Abstracts 139p.

Peterson, N.P. 1980. The role of spring ponds in the winter ecology and natural production of coho salmon (*Oncorhynchus kisutch*) on the Olympic Peninsula, Washington. MS. Thesis, Univ. Wash. Seattle. 96p.

Peterson, N.P. 1982a. Population characteristics of juvenile salmon (*Oncorhynchus kisutch*) overwintering in riverine ponds. Can. J. Fish. Aquat. Sci. 39:1303-1307.

Peterson, N.P. 1982b. Imigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Can J. Fish. Aquat. Sci. 39:1308-1310.

Peterson, N.P. and L.M. Reid. 1984. Wall-based channels: their evolution, distribution, and use by juvenile coho in the Clearwater River, Washington. Pages 215-225 *in* J.M. Walton and D.B. Houston, editors. Proceedings of the Olympic wild fish conference. Peninsula College, Fisheries Technology Program, Port Angeles, Washington.

Platts, W.S. 1991. Livestock grazing. Influences of forest and rangeland management on salmonid fishes and their habitats. Am. Fish. Soc. Special Pub. No. 19. Pages 389-423.

Platts, W.S., K.A. Gebhardt, W.L. Jackson, R.R. Johnson, C.D. Ziebell, D.R. Paton, P.F. Efolliott, and R.H. Hamre. 1985. The effects of large storm events on basin-range riparian stream habitats. USDA For Serv., Intermountain For. and Range Exp. Stn., Gen Tech Rep., Rocky Mt. For. Range Esp. Stn. RM-120. (Abstract Only).

Platts, W.S. and R.I. Nelson. 1985. Streamside and upland vegetation use by cattle. Rangelands 7:5-7.

Poff, N.L. and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Can. J. Fish. Aquat. Sci. 46:1805-1818.

Polzin, M.L. and S.B. Rood. 2000. Effects of damming and flow stabilization on riparian processes and black cottonwoods along the Kootenay River. Rivers. Vol. 7, No. 3. Pp. 221-232.

Poole, G.C., and C.H. Berman. (submitted). Pathways of human influence on water temperature dynamics in stream channels. Environmental Management. 20p

Post, J.R. and D.O. Evans. 1989. Experimental evidence of size-dependent predation mortality in juvenile yellow perch. Can. J. Zool. 67:521-523.

Powell, G.W., K.J. Cameron, and R.F. Newman. 2000. Analysis of livestock use of riparian areas literature review and research needs assessment for British Columbia. Res. Br., B.C. Min. For., Victoria, B.C. Work. Pap. 52/2000.

Power, G., R.S. Brown, and J.G. Imhof. 1999. Groundwater and fish – insights from northern North America. Hydrological Process. 13(3):401-422.

Power, M.E., R.J. Stout, C.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner, and I.R. Wais De Badgen. 1988. Biotic and abiotic controls in river and stream communities. J.N. Am. Benthol. Soc. 7:456-479.

Price, K., D. and McLennan. 2001. Background Report – Hydroriparian Ecosystems of the North Coast. Report prepared for North Coast LRMP, Government of B.C. 90p.

Prowse, T.D. 1994. The environmental significance of ice to cold-regions streamflow. Fresh. Biol. 32:241-260.

Prowse, T.D. and M.N. Demuth. 1996. Using ice to flood the Peace-Athabasca Delta, Canada. Regulated Rivers: Research and Management, 12:447-457

Quinn, T.P. and N.P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington, Can. J. Fish. Aquat. Sci. 53:1555-1564.

Rader, R.B. 1997. A functional classification of the drift: Traits that influence invertebrate availability to salmonids. Can. J. Fish. Aquat. Sci. Vol 54, No. 6, pp.1211-1234.

Raymond, B.A., M.M. Wayne, and J.A. Morrison. 1985. Vegetation, invertebrate distribution and fish utilization of the Campbell River estuary, British Columbia. Can. MS. Rep. Fish. Aquat. Sci. 1829. 46p.

Reid, G.E., T.A. Michalski, T. Reid. 1999. Status of fish habitat in east coast Vancouver Island watersheds. Internal document. Fisheries section, Ministry of Environment, Lands and Parks, 2080 Labieux Road, Nanaimo, B.C., Canada. 38p.

Reid, L.M. 1993. Research and cumulative watershed effects. Gen. Tech. Rep. PSW-GTR-141. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. 118p.

Reimers, P.E. 1973. The length of residence of juvenile fall chinook salmon in Sixes river, Fish Commission of Oregon, research report 4(2);43p.

Reinhardt, U.G. and M.C. Healey. 1997. Size–dependent foraging behaviour and use of cover in juvenile coho salmon under predation risk. Can. J. Zool. 75:1642-1651.

Reiser, D.W. and T.C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in Western United States and Canada. 1. Habitat requirements of adadromous salmonids. USDA. Forest Service. PNW-96. 54p.

Rempel, L.L. 1997. Habitat variation due to seasonal flooding of the lower Fraser River and the influence on the macroinvertebrate community. MSc., Dept Zoology. University of British Columbia, Vancouver, B.C. Canada. 149p.

Resh, V.H., A.V. Brown, A.P. Covich, M.E. Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.D. Wallace and R. Wissmar. 1988. The role of disturbance in stream ecology. J. N. Am. Benthol. Soc. 7:433-455.

Reynolds, P.E. (ed). 1989. Proceedings of the Carnation Creek Herbicide Workshop. Held in Nanaimo, B.C. by Ministry of Forests, Research Branch. 349p.

Richardson, J.S. 1994. Forest-stream interactions: potential effects on productivity and biodiversity of benthic communities in interior British Columbia. Pages 9-14, *In* J.S. Macdonald (ed) Proceedings of the Takla Fishery/Forestry Workshop: a two year review. Can Tech Rep. Fish. Aquat. Sci. 2007:104p.

Richardson, J.S., and C.D. Levings. 1996. Chlorinated organic contaminants in benthic organisms of the lower Fraser River, British Columbia. Water Qual. Res. J. Can. 31(1):153-162.

Riddell, A and G. Bryden. 1996. Courtenay River Water Allocation Plan. Province of British Columbia, Ministry of Environment, lands and Parks, Vancouver Island Region. 51p + Appendix.

Riddell, B.E. and W.C. Leggett. 1981. Evidence of an adaptive basis for geographic variation in body morphology and time of downstream migration of juvenile Atlantic salmon. Can. J. Fish. Aquat. Sci. 38:308-320.

Riehle, M.D. and J.S. Griffith. 1993. Changes in habitat use and feeding chronology of juvenile rainbow trout (*Oncorhynchus mykiss*) in fall and the onset of witner in Silver Creek, Idaho. Can. J. Fish, Aquat. Sci. 50(10):2119-2128.

Rimmer, D.M. U. Paim , and R. L. Saunders. 1983. Autumnal habitat shift of juvenile Atlantic salmon (*Salmo salar*) in a small river. Can. J. Fish. Aquat. Sci. 40:671-680.

Rimmer, D.M., U. Paim , and R. L. Saunders. 1984. Changes in the selection of microhabitat by juvenile Atlantic salmon (*Salmo salar*) at the summer-autumn transition in a small river. Can. J. Fish. Aquat. Sci. 41:469-475.

Rimmer, D.M., and R.L. Saunders. 1984. Effects of temperature and season on the position holding performance of juvenile Atlantic salmon (*Salmo salar*). Can. J. Zool. 63:92-96.

Roberts, R.J. 1979. B.C. salmon survive floods. Fish. News Int., 18(1), 14

Robinson, C.T., L.M. Reed and G.W. Minshall. 1992. Influence of flow regime on life history, production, and genetic structure of *Baetis tricaudatus* (Ephemeroptera) and *Herperoperla pacifica* (Plecoptera). J.N. Am. Benthol. Soc. 11:278-289.

Rogers, H., C.D. Levings. W.L. Lockhart and R.J. Norstrom. 1989. Observations on overwintering juvenile chinook salmon (*Oncorhynchus tshawytscha*) exposed to bleached kraft mill effluent in the upper Fraser River, British Columbia. Chemosphere. 19(12):1853-1868.

Rogers, I.H. and H.W. Mahood. 1983. Thompson River survey. Chemical analysis of water, tissue and sediment samples collected August 1981 to March 1982. Can. Tech. Rep. Fish. Aquat. Sci. 1193: iv + 13p.

Rood, K.M. and R.E. Hamilton. 1994. Hydrology and water use for salmon streams in the Fraser Delta habitat management area, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2238187p

Rood, K.M. and.R.E. Hamilton. 1995a. Hydrology and water use for salmon streams in the Chilliwack/Lower Fraser Habitat Management Area, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2288: 83p.

Rood, K.M. and R.E. Hamilton. 1995b. Hydrology and water use for salmon streams in the Nechako habitat management area, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2299:142p

Rosberg, G.E. and Associates. 1987. Sampling of juvenile salmonids in the Fraser River mainstem over the winter of 1986-1987. Data report for Fisheries and Oceans Canada. DSS File No. 03SB.FP597-6-0603/A. 48p + appendix.

Rosenfield, J.S., S. Macdonald, D. Foster, S. Amrhein, B. Bales, T. Williams, F. Race and T. Livingstone. 2002. Importance of small streams as rearing habitat for coastal cutthroat trout. North American Journal of Fisheries Management. 22:177-187.

Rothacher, J. 1973. Does harvest in west slope Douglas-fir increase peak flow in small forest streams? USDA Forest Service Research Paper, PNW-163. 13p.

Rothrock, J.A. P.K. Barten and G.L. Ingman. 1998. Land use and aquatic biointegrity in the Blackfoot River watershed, Montana. J. Am. Water Resour. Assoc. 34(3):565-583.

Ruggerone, G.T. and D.E. Rogers. 1992. Predation on sockeye salmon fry by juvenile coho salmon in the Chignik Lakes, Alaska: implications for salmon management. North American Journal of Fisheries Management. 12:87-102.

Russell, L.R., C.C. Graham, A.G. Sewid and D.M. Archibald. 1980. Distribution of juvenile chinook, coho and sockeye salmon in Shuswap Lake – 1978-1979; Biophysical inventory of littoral areas of Shuswap Lake, 1978. Can. Fish. Mar. Serv. MS Rep. 1479:54p.

Russell, L.R., K.R. Conlin, O.K. Johansen and U. ORR. 1983. Chinook salmon studies in the Nechako River: 1980, 1981, 1982. Can Manus. Rept. Fish. Aquat. Sci., 1728:185p.

Ryall, R., and C.D. Levings. 1987. Juvenile salmon utilization of rejuvenated tidal channels in the Squamish estuary, British Columbia. Can. Man. Rep. Fish. Aquat. Sci. 1904.

Sabo, M.J., C.F. Bryan, W.E. Kelso, D.A. Rutherford. 1999. Hydrology and aquatic habitat characteristics of a riverine swamp: I. Influence of flow on water temperature and chemistry. Regulated Rivers: Research and Management 15(6):505-523.

Sahin, V., and Hall, M.J. 1996. The effects of afforestation and deforestation on water yields. J. Hydrol. 178:293-309.

Saiki, M.K., B.A. Martin, L.D. Thompson, and D. Welsh. 2001. Copper, Cadmium, and Zinc concentrations in juvenile chinook salmon and selected fish-forage organisims (aquatic insects) in the Upper Sacramento River, California. Water, Air, and Soil Polution. Vol. 132, No. 1-2, pp 127-139.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta).* Pages 231-310 in C. Groot and L. Margolis (ed), Pacific Salmon Life Histories. UBC Press, Vancouver, Canada.

Samis, S.C., S. von Schuckmann, M.T. Wan, G.D. McKellar and M. Scott. 1992. Guidelines for the protection of fish and fish habitat during use of glyphosate and other selected forestry herbicides in coastal British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2176: v + 9p.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 395-446 in C. Groot and L. Margolis (ed), Pacific Salmon Life Histories. UBC Press, Vancouver, Canada.

Scarlett, W.J., and C.J. Cederholm. 1984. Juvenile coho salmon fall-winter utilisation of two small tributaries of the Clearwater River, Jefferson County, Washington. Pages 227-242 *in* J.M. Walton and D.B. Houston, editors. Proceedings of the Olympic wild fish conference. Peninsula College, Fisheries Technology Program, Port Angeles, Washington.

Scarnecchia, D. L. 1981. Effects of streamflow and upwelling on yield of wild coho salmon (*Oncorhynchus kisutch*) in Oregon. Can. J. Fish. Aquat. Sci. 38:471-475.

Schlosser, I.J. 1991. Stream fish ecology: a landscape perspective. Bioscience 41:704-712.

Schluchter, M.D. and J.A. Lichatowich. 1977. Juvenile life histories of Rouge River spring chinook salmon *Oncorhynchus tshawytscha* (Walbaum), as determined by scale analysis. Dept. of Fish and Wildlife. Corvallis Or. Research Section. Information report series. Fisheries; 77-5. 24p.

Schmetterling, D.A., C.G. Clancy and T.M. Brandt. 2001. Effects of riprap bank reinforcement on stream salmonids in the Western United States. Fisheries 26(7):6-23.

Schmitt, C., J. Schweigert and T.P. Quinn. 1994. Anthropogenic influences on fish population of the Georgia Basin. Pages 218-229 *in* R.C. Wilson, R.J. Beamish, F. Aitkens and J. Bell (eds). Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment, Can. Tec. Rep. Fish. Aquat. Sci. 1949:398p.

Scrivener, J.S. and B.C. Andersen. 1994. Stream temperature regimes, possible logging effects, and the implications for salmonids of the Takla Lake/Middle River tributaries. Pages 41 to 45 *in* J.S. Macdonald (*ed*) Proceedings of the Takla Fishery/Forestry Workshop: a two year review. April 1, 1993, Prince George, B.C. Can. Tech. Rep. Fish. Aquat. Sci. 2007:104p.

Scrivener, J.C. and S. Carruthers. 1989. Changes in the invertebrate populations of the main stream and back channels of Carnation Creek, British Columbia following spraying with the herbicide roundup (glyphosate). Pages 263-272 *in* Reynolds, P.E. (ed). Proceedings of the Carnation Creek Herbicide Workshop, Nanaimo, B.C. by Ministry of Forests, Research Branch.

Scrivener, J. C. and T.G. Brown. 1993. Impact and complexity from forest practices on steams and their salmonid fishes in British Columbia, p.41-49. In G. Shooner et S. Asselin (ed). Le Development du Saumon Atlantique au Quebec: connaitre les regles du jeu pour reussir. Colloque International de la Federation Quebecoise pour le Saumon Atlantique. Quebec, decembre 1992.

Scrivener, J.C., T.G. Brown, and B.C. Andersen. 1994. Juvenile chinook salmon (*Oncorhynchus tshawytscha*) utilization of Hawks Creek, a small and nonnatal tributary of the upper Fraser River. Can. J. Fish. Aquat. Sci. 41:1139-1146.

Scott, K.J., M.A. Wheln, L.B. MacDonald, J.D. Morgan and W.R. Olmsted. 1982. 1981 biophysical studies of selected chinook and coho salmon producing tributaries of the North Thompson drainage. Part 1: Juvenile salmon investigations. Fisheries and Oceans, Fisheries Operations. North Vancouver, B. C. March 1982. Dss Contract No. 05SB. FP501-0-180.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada. Bulletin 184.

Seegrist, D. W. and R. Gard. 1972. Effects of floods on trout in Sagehen Creek, California. Trans. Am. Fish. Soc. 101:478-482.

Sedell, J.R. and J.L. Froggatt. 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U.S.A., from its flood-plain by snagging and streamside forest removal. Verh. Internat. Verein. Limnol. 22: 1828-1834.

Sharma, R. and R. Hillborn. 2001. Empirical relationships between watershed characteristics and coho salmon (*Oncorhynchus kisutch*) and smolt abundance in 14 western Washington streams. Can. J. Fish. Aquat. 58:1453-1463.

Sheldon, F. A.J. Boulton and J.T. Puckridge. 2002. Conservation value of variable connectivity: aquatic invertebrate assemblages of channel and floodplain habitats of a central Australian arid-zone river, Cooper Creek. Biological Conservation 103(1):13-31. (Abstract only).

Sheng, M. 1993. Coho habitat restoration and development in the interior of B.C. Pages 318-322 *in* L.Berg and P.W. Delaney (eds). Proceedings of the coho workshop, Nanaimo, B.C., May 26-28, 1992.

Sheng, M.D., M. Foy, and A.Y. Fedorenko. 1990. Coho salmon enhancement in British Columbia using improved groundwater-fed side channels. Can. MS Rep. Fish. Aguat. Sci. 2071:81p.

Shepherd, B.G., J.E. Hillaby, and R.J. Hutton. 1986. Studies on Pacific salmon (*Oncorhynchus* spp.) in Phase 1 of the Salmonid Enhancement Program. Volume II: Data Appendices. Can. Tech. Rep. Fish. Aquat. Sci. 1482: vii + pp 181-364 (Two volumes).

Shirvell, C.S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows. Can. J. Fish. Aquat. Sci. 47:852-861.

Shirvell, C.S. 1994. Effect of changes in stream flow on the microhabitat use and movements of sympatric juvenile coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*) in a natural stream. Can. J. Fish. Aquat. Sci. 51:1644-1652.

Simpkins. D.G. and W.A. Hubert. 2000. Effects of spring flushing flow on the distribution of radio-tagged juvenile rainbow trout in a Wyoming tailwater. N. Am. J. Fish. Manage. 20(2):546-551.

Simpkins, D.G., W. A. Hubert and T.A. Wesche. 2000. Effects of fall-to-winter changes in habitat and frazil ice on the movements and habitat use of juvenile rainbow trout in a Wyoming tailwater. Trans. Am. Fish. Soc. 129(1):101-118.

Singleton, H.J. 1980. Acute toxicity of effluents. Background Report, Fraser River estuary study: water quality. Fraser River Estuary Study Steering Committee. ISSN 0228-5762. 91p.

Skeesick, D.G. 1970. The fall imigration of juvenile coho into a small tributary. Ore. Fish. Comm. Rep. 2(1):90-95.

Smith, B.D. 2000. Trends in wild adult steelhead (*Onchorhynchus mykiss*) abundance for snow melt-driven watersheds of British Columbia in relation to freshwater discharge. Can. J. Fish. Aquat. Sci. 57(2):285-297.

Smith, E.S. 1991 Floodplain management in the Fraser Basin. Pages 115-132, *in* A.H.J. Dorcey (*ed.*), Perspectives on sustainable development in Water Management: Towards agreement in the Fraser Basin. Westwater Research Centre, U.B.C. Vancouver.

Smith, M.A., J.D. Rodgers, J.I. Dodd, and Q.D. Skinner. 1992. Habitat selection by cattle along an ephemeral channel. J. Range Manage. 45:385-390.

Smith, R.W. and J.S Griffith. 1994. Survival of rainbow trout during their first winter in the Henry's Fork of the Snake River, Idaho. Trans. Amer. Fish. Soc. 123:747-756.

Smoker, W.A. 1955. Effects of streamflow on silver salmon production in western Washington Phd dissertation. University of Washington, Seattle.

Sommer, T. B. Harrell, M. Mobriga, R. Brown, P. Moyle, W. Kimmerer, L. Schemel. 2001a. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries, Vol. 26, No. 8. pp. 6-16.

Sommer, T.R., M.L. Nobriga, W.C. Harrel, W. Batham, W.J. Kimmerer. 2001b. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Can. J. Fish. Aquat. Sci. 58(2):325-333.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. Bioscience 45:168-182.

Stanley Associates Engineering Ltd. 1992. Urban runoff quantification and contaminants loading in the Fraser Basin and Burrard Inlet. Environment Canada, coservation and Protection, Fraser Pollution Abatement Office, North Vancouver, B.C. Fraser River Action Plan 93-19.

Stapleford, L. (ed). 1995. An annotated bibliography of research on water quality, habitat loss and water diversion projects affecting British Columbia's fisheries. Report prepared for T. Buck Suzuki Environmental Foundation. #160 – 111 Victoria Drive Vancouver B.C., Canada.214p.

Stay, F.S., A. Katko, K.W. Malueg, M.R. Crouse, S.E. Dominquez and R.E. Austin. 1979. Effects of forest fertilization with urea on major biological components of small Cascade streams, Oregon. Ecol. Res. Series of U.S. Environ. Protect. Agencey, Corvallis Oregon. 68p. (Abstract only).

Steward C. and T. Bjornn. 1989. Response of juvenile chinook salmon to cover in summer and winter. *In* B.G. Shepherd (ed), Proceedings of the 1988 Northeast Pacific chinook and coho salmon workshop. Bellingham Washington. Pages 165-174.

Stewart, G.O., R.B. Lauzier and P.R. Murray. 1983. Juvenile salmonid studies in the North Thompson Region of B.C., 1982. Envirocon Limited, DSS Contract No. 0458 FP 576-1-0487. 134p.

Stevens, V., F. Backhous and A. Eriksson. 1995. Riparian management in British Columbia: an important step towards maintaining biodiversity. Res. Br., B.C. Min. For., Hab. Protect. Br., B.C. Min. Environment, Lands and Parks, Victoria, B.C. Work. Pap 13/1995. 30p.

Stockner, J.G. and K.S. Shortreed. 1976. Autotrophic production in Carnation Creek, a coastal rainforest stream on Vancouver Island, British Columbia. J. Fish Res. Board Can. 33:1553-1563.

Stockner, J.G. and K.S. Shortreed. 1988. The autotrophic community response to logging in Carnation Creek, British Columbia: A six year perspective. Pages 81-86, In: T.W. Chamberlin (Ed.), Proceedings of the workshop: Applying 15 years of Carnation Creek results. Pacific Biological Station, Nanaimo, B.C. 239p.

Stolo 2000. Sumas, a Dynamic Lake. http://web20.mindlink.net/stolo/draing.htm

Sullivan, K., T.E. Lisle, C.A. Dolloff, G.E. Grant and L.M. Reid. 1987. Stream channels--the link between forests and fishes. Pages 39-97. *In* E. O. Salo and T.W. Cundy [ed.]. Streamside management: forestry and fishery interactions. University of Washington, Seattle.

Suzuki, N. and W.C. McComb. 1998. Habitat classification models for beaver (*Castor canadensis*) in the streams of the central Oregon coast range. Northwest Science, 72(2):102-110.

Swain, D.P. and L.B. Holtby. 1989. Differences in morphology and behavior between juvenile coho salmon (*Oncorhynchus kisutch*) rearing in a lake and in its tributary stream. Can. J. Fish. Aquat. Sci. 46(8):1406-1414.

Swales, S. 1982. Environmental effects of river channel works used in land drainage improvement. J. Environ. Manage. 14(2):103-126.

Swales, S. 1988. Utilization of off-channel habitats by juvenile coho salmon (*Oncorhynchus kisutch*) in interior and coastal streams in British Columbia. Verh. Internat. Verin, Limnol. 23:1676.

Swales S. and C.D. Levings. 1989. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. Can. J. Fish. Aquat. Sci. 46(2):232-242.

Swales, S., F. Caron, J.R. Irvine, and C.D. Levings. 1988. Overwintering habitats of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Keogh River system, British Columbia. Can. J. Zool. 66:254-261.

Swales, S., R.B. Lauzier, and C.D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Can. J. Zool. 64:1506-1514.

Swanson, R.H. and G.R. Hillman. 1977. Predicted increased water yield after clear-cutting verified in west-central Alberta. Fish. Environ. Can., Can. For. Ser., North. For. Rest. Cent. Inf. Rep. NOR-X-198.

Swanson, R.J., S.V. Gregory, J.R. Sedell, and A.G. Campbell. 1982. Land-water interactions: the riparian zone. Pages 267 to 291, *in* R.L Edmonds (ed.) Analysis of coniferous forest ecosystems in the western United States. US/IBP Synthesis Series 14. Stroudsburg, PA: Hutchinson Ross Publishing Company.

Symons, P.E.K. 1978. Leaping behavior of juvenile coho (*Oncorhynchus kisutch*) and Atlantic salmon (*Salmo salar*). J. Fish. Res. Board Can., 35(6):907-909.

Szeto, S.Y., G. Grove, H. Liebscher, B.Hii, and B.J. Zebarth. 1994. Nonpoint-source groundwater contamination by 1,2,2-trichloropropane, a trace impurity in soil fumigant formulations. J. Environ. Qual. 23(6)1367-1370.

Taylor, E.B. 1988. Water temperature and velocity as determinants of microhabitats of juvenile chinook and coho salmon in a laboratory stream channel. Trans. Am. Fish. Soc. 117(1):22-28.

Taylor, E.B. 1990. Environmental correlates of life-history variation in juvenile chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). J. Fish. Biol. 37(1):1-17.

Teel, D.J., G.B. Milner, G.A. Winans and W.S. Grant. 2000. Genetic population structure and origin of life history types in chinook salmon in British Columbia, Canada. Trans. Am. Fish. Soc. 129(1):194-209.

Thedinga, J.F. and K.V. Koski. 1984. A stream ecosystem in an old-growth forest in southeast Alaska. Part VI: The production of coho salmon, *Oncorhynchus kisutch*, smolts and adults from Porcupine creek, Pages 99-108 *in* W.R. Meehan, T.R. Merrel, Jr. and T.A. Hanley (eds). Proceedings from a Symposium on fish and Wildlife Relationships in Old-growth Forests. Am. Inst. Fish. Res. Biol., Juneau, A.K.

Thedinga, J.F., M.L. Murphy, J. Heifetz, K.V. Koski, and S.W. Johnson. 1989. Effects of logging on size and age composition of juvenile coho salmon and density of presmolts in southeast Alaska streams. Can. J. Fish. Aquat. Sci. 46:1383-1391.

Thomas, R.B. and W.F. Megahan. 1998. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: a second opinion. Water Resources Research 34(12):3393-3403.

Thornley, S. and A.W. Bos. 1985. Effects of livestock wastes and agricultural drainage on water quality: An Ontario case study. J. Soil Water Conserv. 40(1):173-175.

Toews, D. and M. Brownlee. 1981. A Handbook for Fish Habitat Protection on Forest Lands in British Columbia. Habitat Protection Division, Dept. of Fisheries and Oceans, Vancouver, B.C. 173p.

Toner, M. and P. Keddy. 1997. River hydrology and riparian wetlands: A predictive model for ecological assembly. Ecological Applications. Vol 7, No 1. Pp. 236-246.

Toneys, M.L. and D.W. Coble. 1980. Mortality, hematocrit, osmolality, electrolyte regulation and fat depletion of young of the year freshwater fishes under simulated winter conditions. Can. J. Fish Aquat Sci. 37:225-232.

Top, V., J.C. Nener, B.G. Wernick, B.J. locken and G.A. Derksen. 1997. The influences of intensive agriculture on Matsqui Slough, a south-coastal British Columbia Watershed. Can. Tech. Rep. Fish. Aquat. Sci. 2160:59pp.

Trotter, P.C. 1989. Coastal cutthroat trout: a life history compendium. Trans. Am. Fish. Soc. 118(5):463-473.

Trotter, P.C. 1997. Sea-run cutthroat trout: Life history profile. Pages 7-15, in J.D. Hall, P.A. Bisson, and R.E. Gresswell (eds) Symposium on Sea-Run Cutthroat Trout: Biology, Management, and Future Conservation, Reedsport, Oregon (USA). (Abstract only)

Trimble, S.W. 1994. Erosional effects of cattle on streambanks in Tennessee, U.S.A. Earth surface Processes and Landforms 19(5):451-464.

Triska, F.J., J.R. Sedell, and S.V. Gregory. 1982. Coniferous Forest Streams. Chapter 10, pages 292-332, *In* Edmonds, R.L. (ed), Analysis of Coniferous Forest Ecosystems in the Western United States, US/IBP Synthesis Series 14. Hutchinson Ross Publishing Company; Stroudsburg, PA:

Tschaplinski, P.J. 1982. Aspects of the population biology of estuarine-reared and stream-reared juvenile coho salmon in Carnation Creek: A summary of current research. Pages 289-307 *in* G.F. Hartman (ed.), Proceedings of the Carnation Creek Workshop: A Ten-year Review, Malaspina College, Nanaimo, British Columbia.

Tschaplinski, P.J. 1987. Comparative biology of stream-dwelling and estuarine juvenile coho salmon (*Oncorhynchus kisutch*) in Carnation Creek. Vancouver Island, British Columbia. Ph.D. thesis. University of Vistoria. Victoria, B.C. Canada. 530p.

Tschaplinski, P.J. 1988. The use of estuaries as rearing habitats by juvenile coho salmon. Pages 123-141 *in* T.W. Chamberlin, (ed). Proceeding of the Workshop: Applying 15 Years of Carnation Creek results. Pacific Biol. Station. Nanaimo, B.C.

Tschaplinski, P.J. 2000. The effects of forest harvesting, fishing, climate variation, and ocean conditions on salmomid populations of Carnation Creek, Vancouver Island, British Columbia. Pages 297-327 *in* E. E. Knudsen, C.R. Steward, D.D MacDonald, J.E. Williams and D.W. Reiser, (eds), Sustainable Fisheries Management: Pacific Salmon. Lewis Publishers, Boca Raton, New York.

Tschaplinski, P.J. and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications to survival. Can. J. Fish. Aquat. Sci. 40:452-461.

Tuominen, T., C. Gray, R. Brewer, J. MacRae, B. Raymond, M. Sekela, P. Shaw and S. Sylvestre. Fraser River Action Plan Assessment of contaminant effects on Aquatic ecosystems. Aquatic and Atmospheric Science Division, Environment Canada. Pages 409-415.

Tutty, B.D. 1976. Assessment of techniques used to quantify salmon smolt entrainment by a hydraulic suction hopper dredge in the Fraxer River estuary. Fish. Mar. Serv. Rep. PAC/T-76-16. 35p.

Tutty, B.D. 1979. 1977 chinook investigations associated with the McGregor River diversion. Can. Fish. Mar. Serv. MS Rep. No. 1529:66p.

Tutty, B.D. and F.Y.E. Yole. 1978. Overwintering chinook salmon in the upper Fraser River system. Can. Fish. Mar. Serv. MS Rep. 1450:23p.

UMA Engineering Ltd. 1994. Inventory of municipal stormwater discharges within the Fraser River estuary. Environment Canada, Conservation and Protection. DOE-FRAP 1993-38.

Vannote, R.L. G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Can. J. Fish. and Aquat. Sci. 37:130-137.

Vizcarra, A.T., K.V. Lo, and L.M. Lavkulich. 1997. Nitrogen balance in the lower Fraser River basin of British Columbia. Environ. Manage. (21(2);269-282.

Vought, L.B-M, A. Kellberg and R.C. Petersen. 1998. Effect of riparian structure, temperature and channel morphometry on detritus processing in channelized and natural woodland streams in southern Sweden. Aquat. Conserv.: Mar. Freshwat. Ecosyst. 8(2):273-285. Abstract only.

Waldichuk, M. 1993. Fish habitat and the impact of human activity with particular reference to Pacific salmon. Pages 295-337 *in* L. S. Parsons and W.H. Lear (eds) Perpectives on Canadian marine fisheries management. Can. Bull. Fish. Aquat. Sci. 226.

Walters, C.J. and F. Juanes. 1993. Recruitment limitation as a consequence of natural selection for use of restricted feeding habitats and predation risk taking by juvenile fishes. Can. J. Fish. Aquat. Sci. 50(10):2058-2070.

Walthers, L.C. and J.C. Nener. 1997. Continuous water temperature monitoring in the Nicola River, B.C., 1994: Implications of high measured temperatures for anadromous salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 2158. p65.

Wan, M.T. 1989. Levels of selected pesticides in farm ditches leading to rivers in the lower mainland of British Columbia. Journal of Environmental Science and Health (24)2:183-203.

Wan, M.T.K. and D.M. Wilson. 1976. The impact of mosquito control chemicals on selected non-target organisms in British Columbia. Surveillance report (Canada, Environment Protection Service. Pacific Region. EPS-5-PR-76-3. 59p. (Abstract only).

Wan, M.T., R.G. Watts, and D.J. Moul. 1991. Acute toxicity to juvenile Pacific Northwest salmonids of basacid blue NB755 and its mixture with formulated products of 2,4-D, glyphosate, and triclopyr. Bull. Environ. Contam. Toxicol. 47(3):471-478.

Wan, M.T., S.Y. Szeto, and P. Price. 1995. Distribution and persistence of azinphos-methyl and parathion in chemigated cranberry bogs. Journal of Environmental Quality. Vol 24. No. 4. pp. 589-596.

Ward, P., K. Moore, and R. Kistritz. 1992. Wetlands of the Fraser Lowland, 1989: an inventory. Technical Report Series 146. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia. 216p.

Ward, B.R. and P.A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. Can. J. Fish. Aquat. Sci. 45(7):1110-1122.

Ward, B.R., P.A. Slaney, A.R. Facchin and R.W. Land. 1989. Size-biased survival in steelhead trout (*Oncorhynchus mykiss*): Back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River, British Columbia.. Can. J. Fish. Aquat. Sci. 46(11):1853-1858.

Webb, P.W. 1978. Temperature effects on acceleration of rainbow trout. J. Fish. Res. Bd. Can. 35:1417-1422.

Welcome, R.L. 1979. Fisheries Ecology of Floodplain Rivers. Longman Inc., New York, USA. 317p.

Welty, J.J., T.Beechie, K. Sullivan, D.M. Hyink, R.E. Bilby, C. Andrus, and G. Pess. 2002. Riparian aquatic interaction simulator (RAIS): a model of riparian forest dynamics for the generation of large woody debris and shade. For. Ecol. Manage. 162:299-318..

Wernick, B.G., K.E. Cook, and H. Schreier. 1998. Land use and streamwater nitrate-N dynamics in an urban-rural fringe watershed. J. Am. Water Resour. Assoc., Vol. 34, No. 3, pp.639-650.

West, C.J. and P.A. Larkin. 1987. Evidence of size-selective mortality of juvenile sockeye salmon in Babine Lake, British Columbia. Can. J. Fish. Aquat. Sci. 44:712-721.

Wetlands Network News. 2002. Why Wetlands? Because they provide fish Habitat. 3p. http://www.bcwetlands.com/newsletters/wetnet_news/96_01/why-wetlands-3.html

Whelen, M.A. and D.B. Lister. 1985a. CN twin track project, environmental design program: juvenile salmonid rearing studies, North Thompson River, 1984. Report prepared for CN Rail and Department of fisheries and Oceans. 103p.

Whelen, M.A. and D.B. Lister. 1985b. CN twin track project, environmental design program: juvenile salmonid rearing studies, North Thompson River, 1985. Report prepared for CN Rail and Department of Fisheries and Oceans. 21p.

Whelen, M.A. L.B. MacDonald, J.D. Morgan and W.R. Olmsted. 1982. 1981 biophysical studies of selected chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch)* salmon-producing tributaries of the South Thompson River drainage. Part I – Juvenile salmon investigations. Report DSS Contract No. 05SB. FP501-0-1809. Department of Fisheries and Oceans, Fisheries Operations. 172p.

Whelen, M.A., W.R. Olmsted, and R.W.J. Stewart. 1981. Studies of juvenile chinook salmon (*Oncorhynchus tshawytscha*) and other salmonids in the Quesnel River drainage during 1980. Report prepared for DFO by E.V.S. Consultants Ltd., 105p

Wickett, W.P. 1959. Damage to the Qualicum River stream bed by a flood in January 1958. Progress Reports of the Pacific Coast Stations of the Fisheries Research Board of Canada, issue 113 pp. 16-17.

Whitfield, P.H., N. Rousseau, E. Michnowsky. 1993. Rainfall induce changes in chemistry of a British Columbia coastal stream. Northwest Science 67(1):1-6.

Wikeem, B.M., A. McLean, A. Bawtree, and D. Quinton. 1993. An overview of the forage resource and beef production on Crown land in British Columbia. Can. J. Amim. Sci. 73:779-794.

Wilford, D.J. 1982. Rain-on-snow hydrology in the Queen Charlotte Islands, British Columbia. Province of British Columbia. Memorandum from Smither Research to Director Research Branch Ministry of Forests. August 12. 1982. File 715-19. 13p.

Williams, D.D. and H.B.N. Hynes. 1974. The occurrence of benthos deep in the substratum of a stream. Freshwater Biology, 4:233-256.

Williams, D.D. and H.B.N. Hynes. 1976. The ecology of temporary streams: I. The faunas of two Canadian streams. Int. Revue ges. Hydrobiol. 61:761-787.

Wilson, C.C., R.B. Lewis, A.W. Argue and R.W. Armstrong. 1979. A preliminary salmonid reconnaissance of the Kakweiken River system including trapping and coded-wire tagging of wild coho juveniles, 1977. Fisheries and Marine Service Manuscript Report No. 1497.

Winemiller, K.O. and D.B. Jepsen. 1998. Effects of seasonality and fish movement on tropical river food webs. J. Fish. Biol. 53(A):267-296.

Wood, C.W. 2001. Perspectives on use of best management practices in agriculture. Aquaculture 2001: Book of Abstracts. 699p. (Abstract only)

Wood, CC. B.E. Riddell, and D.T. Rutherford. 1989. Alternative juvenile life histories of sockeye salmon (*Oncorhynchus nerka*) and their contribution to production in the Stikine River, northern British Columbia, pages 12-24. *In* H.D. Smith, L. Margolis, and C.Wood (ed.). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96:486p.

Yee C. S. and T.D. Roelofs. 1980. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America. 4. Forest Roads. USDA. Forest Service. PNW-109.

Young, G.J. 1980. Monitoring glacier outburst floods. Nord. Hydrol., 11(5):285-300.

Young, K.A. 2000. Riparian zone management in the Pacific Northwest: Who's cutting what? Environ. Manage. 26(2):131-144.

Young, K.M. 1998. Absence of autumnal changes in habitat use and location of adult Colorado River cutthroat trout in a small stream. Trans. Am. Fish. Soc. 117(1):147-151.

Zarnowitz, J.E., and K.J. Raedeke. 1984. Winter predation on coho fingerlings by birds and mammals in relation to pond characteristics. Service Contract No. 1480. Washington Dept. of Fisheries, Habitat Management Division, Olympia.34p.

Zebarth, B.J. J.W. Paul and R. Van Kleeck. 1999. The effect of nitrogen management in agricultural production on water and air quality: evaluation on a regional scale. Agric. Ecosyst. Environ. 72(1)35-52.

Zufelt, J.E. and M.A. Bilello. 1992. Effects of sever freezing periods and discharge on the formation of ice jams at Salmon, Idaho. Cold Regions Research and Engineering Lab., Hanover, NH (USA). NTIS Order No. AD-A255 876/5/GAR. Abstract only

Zuzel, J.F. R.N. Greenwalt, and R.R. Allmaras. 1983. Rain-on-snow: shallow, transient snowpacks with frozen soils. Proc. of 51st Annual Western Snow Conference, Vancouver, Washington pp. 676-75.

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Unpublished Data Sources

Brown, T.G. data	--- From Carnation Creek Study. (1984-1987)
	--- From Black Creek Study (1998-1999)
	--- From Shuswap Lake Study (1999-2001)
	--- Demaniel Creek (2000-2001)